

AD-A056 263

AERONAUTICAL RESEARCH LABS MELBOURNE (AUSTRALIA)  
OPTICAL AIDS FOR PILOT-CONTROLLED HOVERING OF LIGHT HELICOPTERS--ETC(U)  
APR 77 B A CLARK

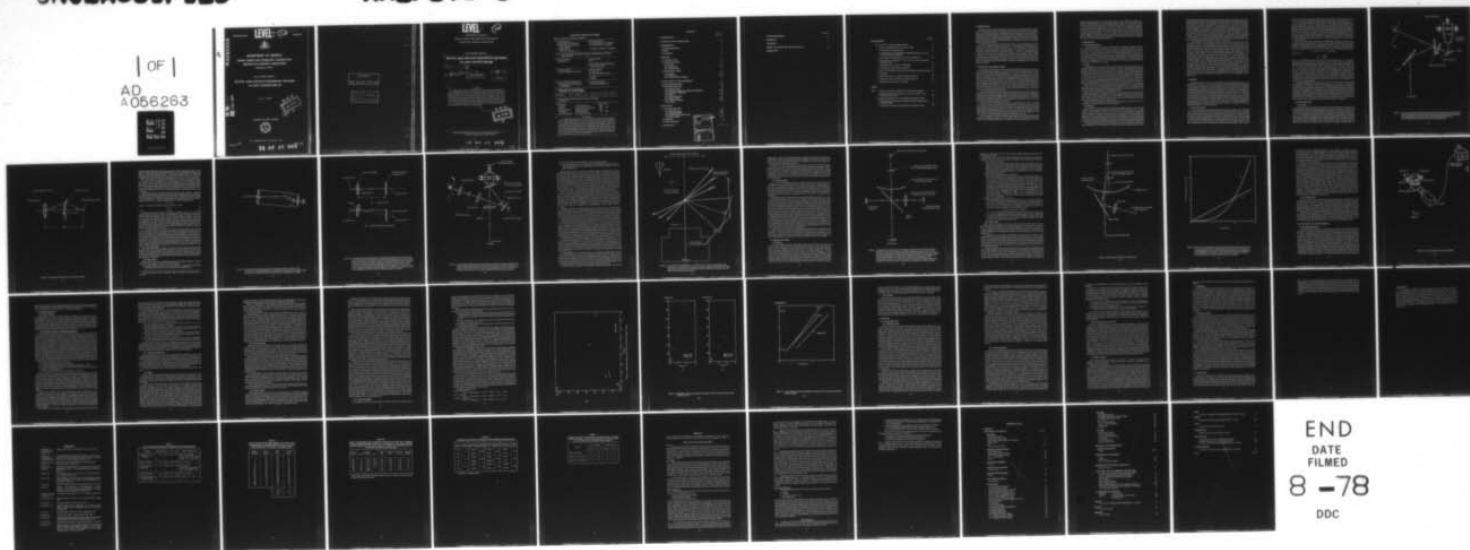
F/G 1/3

UNCLASSIFIED

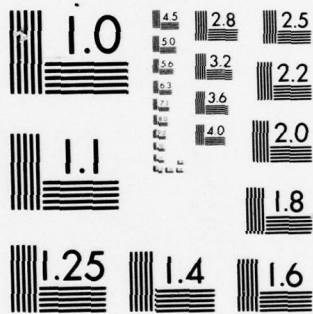
ARL/SYS-8

NL

| OF |  
AD  
A056263



END  
DATE  
FILMED  
8 -78  
DOC



MICROCOPY RESOLUTION TEST CHART  
NATIONAL BUREAU OF STANDARDS-1963-A

**LEVEL** *11.*

*(12)*



**DEPARTMENT OF DEFENCE**

**DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION**

**AERONAUTICAL RESEARCH LABORATORIES**

**MELBOURNE, VICTORIA**

ARL SYSTEMS REPORT 8

**OPTICAL AIDS FOR PILOT-CONTROLLED HOVERING  
OF LIGHT HELICOPTERS (U)**

B. A. J. CLARK



Approved for Public Release



© COMMONWEALTH OF AUSTRALIA 1977

COPY No **16**

APRIL 1977

**78 07 17 038**

**AD A056263**

**AU NO. \_\_\_\_\_  
DDC FILE COPY**

APPROVED  
FOR PUBLIC RELEASE

THE UNITED STATES NATIONAL  
TECHNICAL INFORMATION SERVICE  
IS AUTHORIZED TO  
REPRODUCE AND SELL THIS REPORT



# LEVEL

(12)

DEPARTMENT OF DEFENCE  
DEFENCE SCIENCE AND TECHNOLOGY ORGANISATION  
AERONAUTICAL RESEARCH LABORATORIES

ARL SYSTEMS REPORT 8

**OPTICAL AIDS FOR PILOT-CONTROLLED HOVERING  
OF LIGHT HELICOPTERS (U)**

(9) Systems ref.

(14) ARL/SYS-8

by

(10) B. A. J. CLARK

(11) APR 77

(12) 49p

ABSTRACT

SUMMARY

In certain military and civil tasks such as surveying, construction and surveillance it may be helpful if light helicopters can be hovered precisely above some selected point on the ground. Depending on the task, the height above ground and the nature of the terrain, hovering precision may be limited by the pilot's lack of adequate visual cues to the helicopter's position and motion in the horizontal plane. This report introduces several optical methods of providing the visual cues and describes some practical results for one device which has been called the Hoversight. This device allows an improvement by a factor of 4.5 in the horizontal accuracy of hovering at 600 m above a designated ground point. Further improvements in accuracy seem feasible. (U)

ABSTRACT



POSTAL ADDRESS: Chief Superintendent, Aeronautical Research Laboratories,  
P.O. Box 4331, Melbourne, Victoria, 3001, Australia.

10 07 16 038

008 650

JOB

# DOCUMENT CONTROL DATA SHEET

Security classification of this page: Unclassified

- |   |  |
|---|--|
| <p>1. Document Numbers</p> <p>(a) AR Number: AR-000-722</p> <p>(b) Document Series and Number:<br/>Systems Report 8</p> <p>(c) Report Number:<br/>ARL-SYS.—Report—8 ✓</p> | <p>2. Security Classification</p> <p>(a) Complete document: Unclassified</p> <p>(b) Title in isolation: Unclassified</p> <p>(c) Summary in Isolation: Unclassified</p> |
|---|--|

3. Title: OPTICAL AIDS FOR PILOT-CONTROLLED HOVERING OF LIGHT HELICOPTERS ✓

- |   |                                     |
|---|-------------------------------------|
| <p>4. Personal Author(s):<br/>Clark, Barry A. J.</p>                    | <p>5. Document Date:<br/>1977 ✓</p> |
| <p>6. Type of Report and Period Covered:<br/>Final Technical Report</p> |                                     |

- |   |   |
|---|---|
| <p>7. Corporate Author(s):<br/>Aeronautical Research Laboratories</p> | <p>8. Reference Numbers</p> <p>(a) Task: 71/6</p> <p>(b) Sponsoring Agency: RD/73</p> |
|---|---|

9. Cost Code:  
73-6980

- |  |   |
|--|---|
| <p>10. Imprint (Publishing establishment):<br/>Aeronautical Research Laboratories,<br/>MELBOURNE</p> | <p>11. Computer Program(s)<br/>(Title(s) and language(s)) Nil</p> |
|--|---|

12. Release Limitations (of the document):  
**Approved for Public Release**

12-0. Overseas:	No.		P.R.	I	A		B		C		D		E	
-----------------	-----	--	------	---	---	--	---	--	---	--	---	--	---	--

13. Announcement Limitations (of the information on this page):  
No Limitation

- |   |  |
|---|--|
| <p>14. Descriptors:</p> <p>Helicopters                      Air Drop Operations</p> <p>Hovering                         Human Factors Engineering</p> <p>Optical Equipment             Shipboard Landing</p> <p>Gyroscopes                    Pilot Performance</p> <p>Television Guidance            Surveying Instruments</p> | <p>15. Cosati Codes:</p> <p>0103</p> <p>0505    1402</p> <p>1507</p> <p>1707    2006</p> |
|---|--|

16.

## SUMMARY

*In certain military and civil tasks such as surveying, construction and surveillance it may be helpful if light helicopters can be hovered precisely above some selected point on the ground. Depending on the task, the height above ground and the nature of the terrain, hovering precision may be limited by the pilot's lack of adequate visual cues to the helicopter's position and motion in the horizontal plane. This report introduces several optical methods of providing the visual cues and describes some practical results for one device which has been called the Hoversight. This device allows an improvement by a factor of 4.5 in the horizontal accuracy of hovering at 600 m above a designated ground point. Further improvements in accuracy seem feasible. (U)*

## CONTENTS

	Page No.
1. INTRODUCTION	1
2. LITERATURE AND EARLIER WORK	1-2
3. REQUIREMENTS	2
3.1 Physical Characteristics	2
3.2 Safety	2
3.3 Performance	2-3
4. METHODS	3
4.1 Fixed Mirror System	3-4
4.2 Stabilized Plane Mirror	4
4.2.1 Concept	4-7
4.2.2 Visual version	7-13
4.2.3 Television version	13
4.3 Stabilized Convex Mirror	13
4.3.1 Concept	13-15
4.3.2 Visual version	15-18
4.3.3 Television version: Hoversight	18
5. FLIGHT TRIALS OF THE HOVERSIGHT	18
5.1 Initial Flight Demonstration	18-20
5.2 Instrumented Flight Trials	20
5.2.1 Choice of aircraft	20
5.2.2 Hoversight reconstruction, calibration and installation	20-21
5.2.3 Arrangement of flight trials	21
5.2.4 Flights	21-22
5.2.5 Observations of pilot	22
5.2.6 Analysis of films	22-23
5.2.7 Analysis of videotapes	23-28
5.2.8 Comments	28
6. DISCUSSION	
6.1 Hoversight Flight Trials	28
6.1.1 Horizontal accuracy	28-29
6.1.2 Altitude maintenance	29-30
6.1.3 Hovering accuracy in other trials	30
6.1.4 Pilot's comments	30-31
6.2 Applications	31
6.3 Further Development	31
7. CONCLUSIONS	31-32

ACCESSION for	
NTIS	White Section <input checked="" type="checkbox"/>
DDC	Buff Section <input type="checkbox"/>
UNANNOUNCED	<input type="checkbox"/>
JUSTIFICATION	
BY	
DISTRIBUTION/AVAILABILITY CODES	
Dist.	Special
A	

	Page No.
<b>ACKNOWLEDGEMENTS</b>	33
<b>REFERENCES</b>	34
<b>APPENDICES</b>	
<b>Appendix 1: Extract from ARDU Report TI453 (Ref. 15).</b>	40
<b>DISTRIBUTION</b>	



	Page No.
<b>ILLUSTRATIONS</b>	
Fig. 1 Fixed-mirror system for helicopter hovering	5
2 Analysis of plumb-point error in two-mirror system	6
3 The principle of automatic levelling	8
4 A simple method for compensating for misalignment between the axis of a surveying level and the horizontal	9
5 Gyroscopically stabilized plane-mirror vertical viewing device	10
6 Image positions corresponding to $-12^\circ$ , $0^\circ$ , and $+12^\circ$ tilt of the stabilized plane-mirror sight	12
7 Arrangement of a convex-mirror vertical sight	14
8 Ray paths with the convex-mirror sight tilted	16
9 Errors in tilt compensation of the convex-mirror sight as a function of tilt angle	17
10 Hoversight	19
11 Observations of $R_{0.5}$ as a function of altitude, monitor off	25
12 Observations of $R_{0.5}$ as a function of altitude, monitor on	26
13 Regression lines for $\log R_{0.5}$ v. $\log$ altitude	27

## TABLES

Table	I Mass, size and electrical requirements of the prototype Hoversight	35
	II Observations of amount of time spent by the pilot in looking at the Hoversight monitor screen	36
	III Results of measurements of films recorded from the ground station	37
	IV Comparisons between measures of helicopter movement calculated from ground-based films	38
	V Comparisons of accuracy of hovering above a given ground target	39

## 1. INTRODUCTION

Accurate surveying by aerial photography usually requires that each photograph include one or more features for which the position is known from precise ground survey. In jungle, swamp or mountainous terrain, the establishment of these control points may be difficult or impossible by conventional ground survey methods because of inordinately long travel times or obstructions in the line of sight from previously measured points. These problems can be largely overcome by observation, from existing control points, of a helicopter that is hovered at a suitable altitude vertically above the feature being determined. This method is known as the Airborne Survey Control System (ASCS).

The nature of the task with the ASCS may prevent the use of ground-based aids to precise hovering, so that a practical airborne aid may allow a useful extension of the technique. Such an aid may well find uses in other helicopter work, e.g. civil and military construction and surveillance. This report describes several approaches to the problem of providing airborne visual aids that allow helicopters to be hovered with improved precision in the horizontal plane. As operators' acceptance of new devices will be influenced by the cheapness and simplicity of the devices as well as by actual performance, the use of servo-controlled devices has been avoided and effort concentrated on the only currently practicable alternative, gyroscopes with direct attachment of optical elements. The idea, of course, is to provide the pilot with an indication of the ground point vertically beneath the helicopter, independently of the helicopter's attitude and motion.

## 2. LITERATURE AND EARLIER WORK

The accuracy of determination of position with the ASCS method is limited by the accuracy with which the helicopter's position can be related to the vertical extending up from the feature selected for measurement. Helicopter characteristics in the event of engine failure are often such that it may be unsafe to hover between about 5 and 150 m above ground unless a strong surface wind is present, so that the helicopter is generally required to hover above 150 m. This seems too far from the ground for pilots to make a sufficiently accurate assessment of horizontal rate and position from visual observation of the terrain: in one previously unpublished experiment, experienced pilots without hovering aids were unable or unwilling to keep the ground speed of their Bell 47G helicopters below about 4 m/s when attempting to hover at 150 m, and the horizontal excursions from the desired vertical were correspondingly large. The pilot in one of the more recent trials described below did considerably better, however, although he was flying the larger Bell UH-1B (Iroquois).

In an early method of hovering for ASCS purposes, the pilot was provided with a gyro-stabilized vertical tube through which he could see the ground below with unit magnification. Hovering errors with this device limited operation to altitudes below 200 m (Ref. 1). Presumably the pilot would experience some difficulty with this device because visual reference to the horizon would be lost in looking vertically down, and restriction of the visual field is known to increase the likelihood of pilot disorientation (e.g. Ref. 2).

In another previously unpublished experiment, hovering guidance was given by coloured sectors projected vertically upwards from the ground and a 0.75 m square mirror was mounted on the canopy in front of the pilot specifically so that he could see the light source on the ground while retaining parafoveal visual reference to the horizon. The technique failed mainly because of the difficulty of distinguishing variation in the colour of a point source seen against a sunlit background, and the relative coarseness of the rate and position information supplied by various colour, intensity, and flicker-frequency modulation systems that were tried.

After the inadequacy of the ground-based projected light system had been demonstrated, a television guidance system (Ref. 3) was developed for ASCS work. Although this system also makes use of ground-based equipment, it is nevertheless worth mentioning because its use has



provided important information on the ability of pilots to hover helicopters precisely when aided by suitable information. The ground-based television system has a camera fitted with a zoom lens aimed vertically upward, and the picture is transmitted to a receiver screen mounted in front of and facing the helicopter pilot. A wide field of view is used for initial positioning and the magnification is increased progressively with the zoom lens as the helicopter is guided by the pilot to the central graticule on the receiver screen. Aided by this system, pilots were able to maintain the helicopter within 1.2 m of the indicated vertical for minutes at a time at 1200 m altitude, sufficient for theodolite and microwave distance measurements, and precise hovering above the 2400 m altitude actually tried seems quite feasible. More recent trials have confirmed the order of accuracy originally reported (Ref. 4).

### 3. REQUIREMENTS

#### 3.1 Physical Characteristics

An all-airborne type of hovering aid would presumably find application in light helicopters, that is, helicopters capable of carrying a useful load of a few hundred kilograms, and these helicopters are usually not fitted with stability augmentation systems because of the excessive mass penalty. A similar consideration applies to any proposed hovering aid; if its mass is say 10 kg it could be acceptable but 100 kg may not be. Linear dimensions of the aid should also be limited because of the restricted space available in light helicopters. The aid should be quiet in operation because the sound pressure levels in most helicopter cabins are already unpleasantly high. Ease of maintenance and low cost are desirable, as otherwise the aid could be beyond the resources of light helicopter operators.

#### 3.2 Safety

It seems unlikely that any fully automatic control system for hovering could meet all of the foregoing requirements, so that any system proposed with these requirements in mind would probably include the pilot as part of the control loop. At present, most light helicopters are not inherently stable enough to be flown 'hands off' for any length of time, if at all, and therefore any equipment used by the pilot should not distract him, feed him conflicting or false information, or in any other way prevent him from maintaining full control of the helicopter. If the pilot is hovering with the help of the device and a need arises for the helicopter to be moved quickly, e.g. out of the way of an approaching aircraft (this happened several times during the development of the ground-based television hovering aid), then the time for transition from hover to translational flight should not be extended by virtue of any characteristic of the hovering aid.

Failure of any part of a hovering aid should not endanger the helicopter. The aid should be structurally safe, and any electrical circuits should be isolated as far as practicable from the helicopter's electrical system, at least during the development of the system, and the aid should not generate electrical interference to communication systems.

Restriction of the pilot's visual field in helicopters is an important cause of disorientation, a factor in many helicopter crashes (Ref. 2), so that hovering aids should not cause any appreciable restriction of the visual field. The use of an aid should not cause undue restriction of the pilot's head movements as this could lead to early fatigue, and crash safety requires that equipment should not be located close to the pilot's face.

Some of the above requirements could be relaxed if two pilots are used but this may not be operationally practicable on logistic or economic grounds.

#### 3.3 Performance

The accuracy of helicopter positioning with the ground-based television system was good enough for many purposes in surveying. Although the horizontal distances from a selected vertical could be maintained within one or two metres at the altitudes flown, concomitant control of altitude was less exact in the initial trials as it depended only on the indication from the helicopter's ordinary altimeter. Instruments much more sensitive to alterations in (pressure) altitude are used in sailplanes (pneumatic or electronic variometers) and in aerial photography (statoscope, e.g. Ref. 5), and subsequent trials with a sensitive vertical speed indicator mounted next to the pilot's monitor screen did allow improved control of altitude during hovering (Ref. 4).

With the ground-based television system, position errors of the helicopter in the horizontal plane depended firstly on the accuracy with which the vertical was established for the ground-

based camera and secondly on the accuracy with which the pilot could maintain a given point on the helicopter coincident with the graticule mark on the monitor screen. If the camera axis deviated from the vertical by some small angle  $\theta$ , then the first error is  $\theta h$  where  $h$  is the altitude above ground; in practice  $\theta$  was about 0.1 mrad. The second error was found to be roughly inversely proportional to the magnification of the helicopter on the monitor screen, and for a given focal length of camera lens, this error would also increase proportionally with altitude. With a suitable lens, the second error amounted to 0.001  $h$  for a Bell 47G helicopter, i.e. about ten times larger than the error due to non-verticality of the camera. The effect on surveying accuracy of this second error could be eliminated completely in some instances by photographing a monitor screen or by otherwise noting the helicopter's displacement from the graticule mark at the instant that some positional measurement was made, then using the measured displacement of the helicopter from the mark as a correction to the results.

It seems unlikely that any simple fully airborne hovering system could allow an accuracy comparable with that of the ground-based television system. The vertical orientation of the ground-based camera was set by reference to an optical system that was itself set by observation of the reflection from a mercury bath. Indication of the vertical in a fully airborne system could hardly be expected to be as precise. One possible method would be based on observation of the horizon or celestial objects, but cloud would frequently interfere with observations. A more practicable method would be to use an aircraft vertical gyroscope (attitude indicator). As a typical modern vertical gyro indicates the vertical within about  $\pm 0.2^\circ$  ( $\pm 3.5$  mrad) (Refs. 6, 7), the fully airborne system is likely to have errors at least three or four times larger than those of the ground-based system. Although better accuracy could be desirable, an airborne system nevertheless appears to offer sufficient promise for enough purposes to warrant some investigation. For example, hovering at 200 m altitude would mean a gyroscope contribution to the horizontal errors of about 0.7 m, still small enough for many survey purposes. At an altitude of 2000 m, sufficiently high to avoid the hazard of hostile small-arms fire from the ground, stores dropping could be performed within 7 m of the vertical from a target point nominated by troops on the ground. This would appear to be adequate even if the dropping zone were in jungle. In any case, offset corrections for the aerodynamics of the stores to be dropped, for wind speed and for motion of the helicopter may preclude effective use of any improvement in instrument accuracy.

#### 4. METHODS

The present problem is related to a basic problem in aerial photogrammetry, that is, the determination of the vertical in an aircraft subject to unknown small attitude changes during aerial photography. Pendulous mounting of aerial cameras is of little use because of continual small horizontal accelerations of the aircraft. Subject to certain conditions, e.g. overlapping of photographed areas and the existence of ground control points, it is possible to use the information on each photograph to determine the precise orientation of the camera at the instant of exposure. The alternative methods of actively controlling the camera orientation (Ref. 7), or of recording its orientation by gyroscopic or other means have been pursued since the earliest days of aerial photography (Ref. 8) but the lack of practical acceptance of these many attempts is best indicated by the continuing widespread use of fixed aerial cameras, some of which have image-motion compensation but only for the forward movement of the aircraft. It seems that techniques from aerial photography are unlikely to provide a practical solution to the problem of devising a simple fully airborne aid for precise hovering.

##### 4.1 Fixed Mirror System

In trials of the ground-based projected light system mentioned in Section 2 above, the image of the ground beneath the aircraft was reversed in the fore-and-aft direction. Thus the image seen by the pilot in the single mirror moved upwards when the aircraft was moving forwards, but tilting of the helicopter associated with forwards acceleration tended to cancel or over-ride the image movement, and deceleration to increase it. Acceleration to the right moved the image to the right but the subsequent motion of the helicopter shifted the image to the left. While the pilot concentrated on the indications of the light projector on the ground, the motion of the mirror image and the motion of the peripheral visual field provided multiple conflicts of percep-

tual cues. Such conflicts are particularly undesirable for helicopter pilots. This is possibly a further reason why the pilots were unable to succeed with the vertical beam viewed in the mirror.

In one type of gyro-stabilized drift meter (Ref. 9), the image of the ground beneath the aircraft is unstabilized, that is, its location depends on the attitude of the aircraft, but the graticule used for measuring drift is stabilized and thus maintains its position with respect to the image of the ground. The possibility arises that a similar system could be of use for the present problem. To avoid the necessity of having the pilot physically looking vertically downward, a pair of mirrors arranged as in Figure 1 would allow simultaneously a parafoveal view of the horizon and instrument panel, and the image seen by the pilot would correspond to the appearance of a map correctly orientated. The plumb point on the ground (i.e. the point vertically below) would be indicated by the collimated image of a graticule suspended from the rotor housing of a vertical gyroscope.

Figure 2 shows the optical arrangement of the plumb-point indication. The plane mirror shown as part of this system in Figure 1 is fixed with respect to the collimating lens so that it may be ignored in analysing the errors of the plumb-point indication. A unity scale factor between  $\theta$  and  $\phi$  is a necessary condition for correct indication of the plumb point. This is achieved for small values of  $\theta$  and  $\phi$  if  $p = f'$ , but then at larger angles,  $\theta$  and  $\phi$  will differ appreciably because

$$h = p \sin \theta = [f' + p(1 - \cos \theta)] \tan \phi$$

and with  $f' = p$ ,

$$\tan \phi = \frac{\sin \theta}{2 - \cos \theta}.$$

For  $\theta = 10^\circ$ , a representative value of helicopter tilt while manoeuvring,  $\phi = 9.7^\circ$ . The difference between  $\theta$  and  $\phi$  in this case is thus an error of  $0.3^\circ$  or about 5 mrad. This would be acceptably small for many purposes, but smaller errors are possible by making  $p$  slightly greater than  $f'$  so that  $\theta$  and  $\phi$  become equal at some suitable value of  $\theta$ , say  $10^\circ$ . For instance, with  $p = 1.03f'$ , the error at  $0^\circ$  and  $10^\circ$  is zero and it passes through a maximum of 1.8 mrad near  $7^\circ$ . Other sources of inaccuracy are the intrinsic error of the gyroscope in wandering from the true vertical, systematic error introduced by incorrect adjustment of the graticule in its own plane, and errors introduced by aberrations of the collimating lens and non-flatness of the three mirrors. It seems that the net systematic error could easily be reduced to less than 0.3 mrad, the resolving power of the human eye, so that among the factors limiting performance with this system in use would be the unit magnification of the pilot's view of the ground and the intrinsic error of the gyroscope.

An inherent difficulty with the fixed mirror system is the movement of the ground image and its plumb-point indication as the helicopter attitude alters. For large tilts, the plumb-point will disappear out of the field of view, and even if the pilot moves his head in an attempt to recover this point the plumb-point indication may not be visible because of practical restrictions on the size of the collimating lens. Disorientation or other unpleasant consequences of conflicting information from different parts of the visual field would presumably be more likely if large and frequent changes in helicopter attitude took place during hovering. On the other hand, if attitude changes were sufficiently small and slow then the system might prove quite satisfactory. There seems to be no existing way of determining how acceptable this type of device should prove in practice, apart from actual trials with the device installed in a helicopter.

## 4.2 Stabilized Plane Mirror

### 4.2.1 Concept

Experience resulting from trials of some of the devices mentioned above has reinforced an earlier expectation that a stabilized image of the terrain beneath the helicopter would be more acceptable to pilots than the unstabilized image seen via fixed mirrors. Textbooks and journals on optics seem remarkably devoid of discussion on methods of stabilizing optical images, however. The one exception is the stabilization of the retinal image on the retina, but these techniques appear to be inapplicable to the present problem. Mention is made in Reference 10 of two methods of compensation for image displacement in surveying instruments, the usual method (discussed below) and the author's liquid-prism optical plummet (Ref. 11) which was actually tried in a helicopter but without much success because it responds to the apparent vertical indicated by



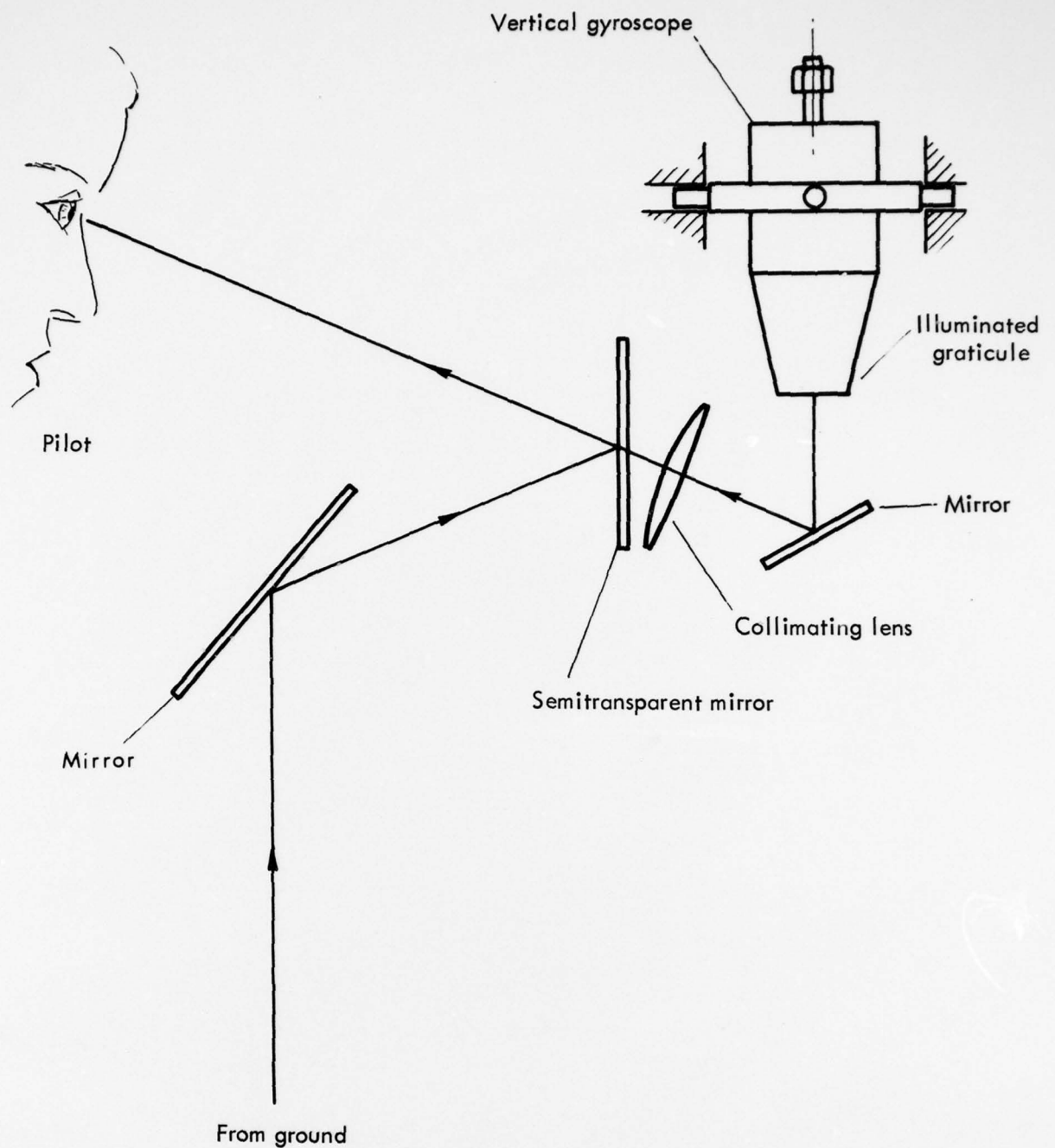


Figure 1 Fixed-mirror system for helicopter hovering. The illuminated graticule would be seen by the pilot superimposed on the ground, indicating the plumb point. The distance from the graticule to the centre of the vertical gyroscope gimbal system is approximately equal to the focal length of the collimating lens.

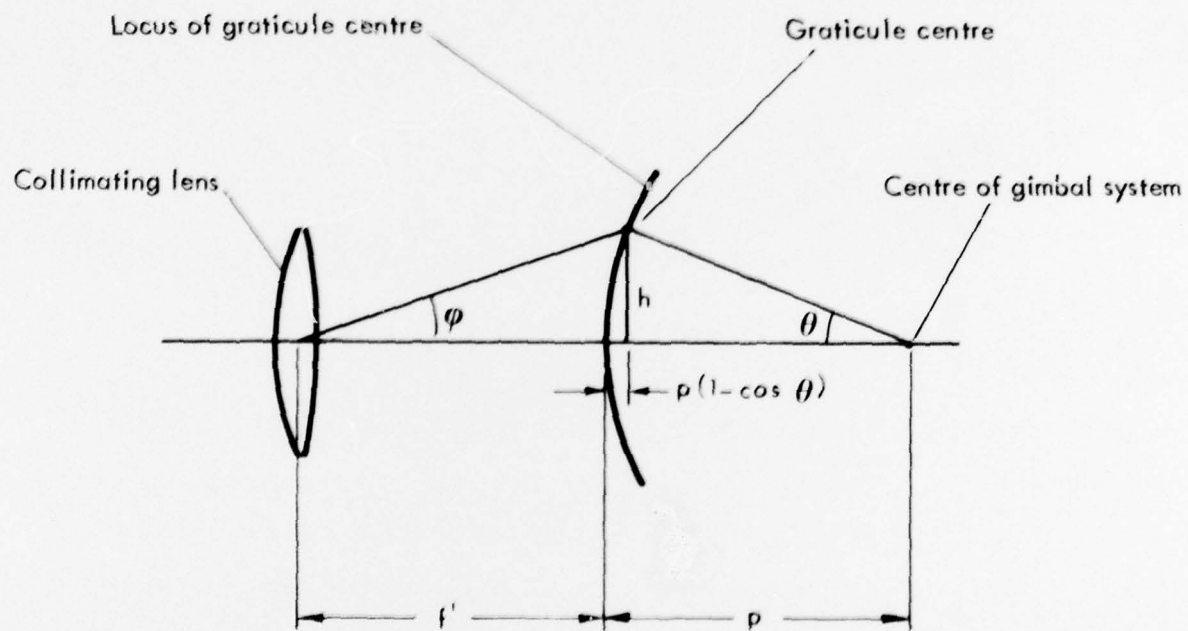


Figure 2 Analysis of plumb point error in two-mirror system.

gravitational and inertial forces with a lag introduced by viscous damping. Servocontrol of the device by a vertical gyroscope presumably would work, but a servocontrolled (by image-motion detection) single liquid-prism device that is commercially available\* (Ref. 12) or electronic compensation by raster movement (Ref. 12) could be used only if slow drift of the image and no indication of the plumb-point were acceptable, which, of course, is not the present case.

The usual technique of image-motion compensation in surveying instruments normally gives compensation in one direction only and the compensation is for image position rather than motion, i.e. static rather than dynamic. The instruments in question are called automatic levels; by setting them approximately horizontal, the telescopic image is automatically brought to a position where the fixed graticule in the eyepiece indicates the horizontal precisely. Compensation for levelling error serves the purpose of saving time in setting up the level at each new location.

The principle of automatic levelling can be understood by reference to Figure 3. A telescope, set roughly horizontal, makes an angle  $\alpha$  with the horizontal. The horizontal ray passing through the centre of the objective is deviated through an angle  $\beta$  by a compensating device at  $C$ . Regardless of the magnitude of  $\alpha$  within its working range of a few minutes of arc, the angle  $\beta$  is just sufficient to direct the ray through the graticule centre. As shown in Reference 10,

$$\beta = n\alpha \quad (1)$$

where  $n$  is a constant. From Figure 3, if  $OG = f$  and  $CG = s$ , then

$$\beta s \approx \alpha f \quad (2)$$

so that

$$n \approx f/s. \quad (3)$$

Compensators often take the form of pendulous assemblies of prisms or mirrors. The simplest of these forms utilizes a single mirror suspended so as to remain vertical. As the angle between incident and reflected ray for a mirror is twice the angle of incidence, in this case  $n = 2$  and the mirror is therefore placed midway between lens and focus (Fig. 4). The image is inaccessible for observation with the arrangement of Figure 4. Practical considerations require the suspended mirror merely to make a constant angle with the vertical so that the focus of the horizontal rays maintains a fixed position alongside the mechanical mounting of the objective. Surveying instruments generally have at least one additional fixed mirror or prism to bring the image to a convenient position for viewing.

If the system of Figure 4 is mounted with the optical axis approximately vertical and the mirror is maintained precisely horizontal, then a distant point positioned vertically under the lens will be imaged at the second principal point of the lens regardless of small inclination of the lens and its mounting, or large inclination provided that the change of lens to mirror distance with inclination has been chosen to suit the field curvature. This compensation will apply for any direction of the inclination with the vertical, so that the device provides two-dimensional compensation, unlike surveying levels where introduced shifts of the image in the horizontal direction may be undesirable and are therefore eliminated as far as possible by the design. This device constitutes an automatic optical plummet, and the next stage is to investigate its application to the hovering problem.

If gyroscopic stabilization is applied to the mirror of the automatic optical plummet described in the previous paragraph, the remainder of the optical system can be fixed to the helicopter. The advantage of this is that a plane mirror of the size required can have a much smaller mass and moment of inertia than the complete optical system, so that the direct mounting of components on the gyroscope rotor housing is much more likely to prove practicable if only the mirror has to be mounted.

#### 4.2.2 Visual version

Figure 5 shows a layout of a hovering aid based on the stabilized orientation of a plane mirror. This layout appears to have several important features:

- (a) The image viewed by the pilot is erect and corresponds in orientation with the picture of the ground that would be seen if he could see down through his floor.

---

\* S-023 Dynalens Image Motion Compensator Sight, Dynasciences Corporation, Pennsylvania USA.



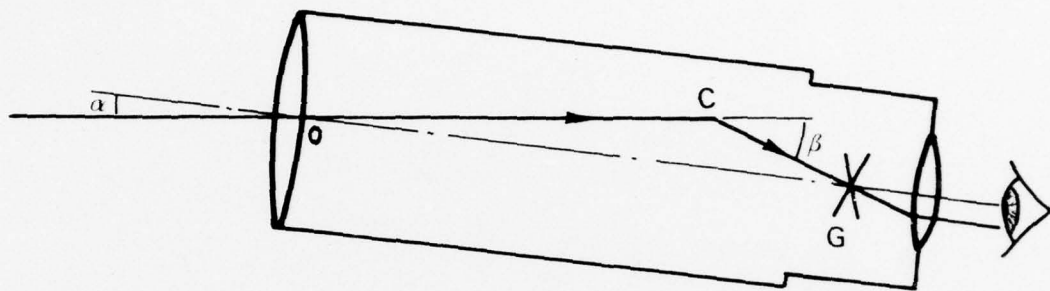


Figure 3 The principle of automatic levelling. The telescope is tilted at an angle  $\alpha$  to the horizontal, but a compensating device at C deviates the horizontal ray through an angle  $\beta$  so that the ray meets the centre of the graticule at G. (Redrawn from Ref.10.)

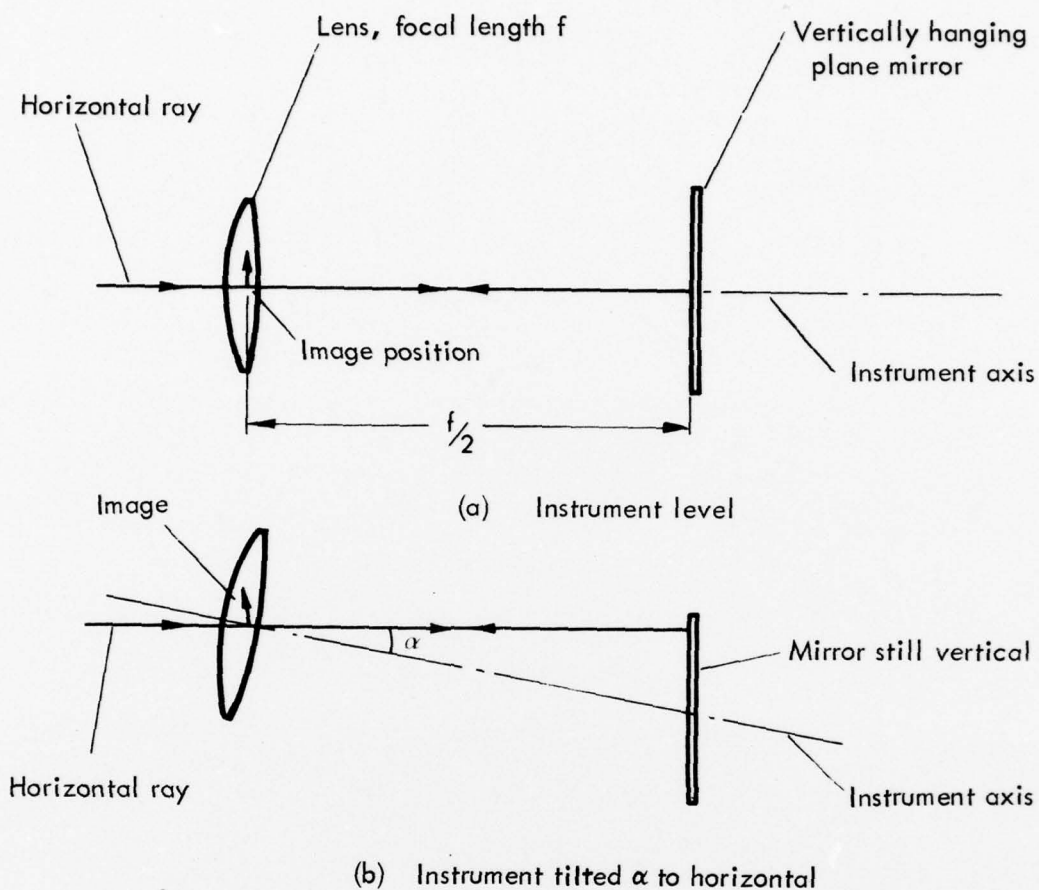


Figure 4 A simple method of compensating for misalignment between the axis of a surveying level and the horizontal. The plane mirror is mounted pendulously so that it is free to rotate in the plane of the diagram, attaining a vertical orientation under the influence of gravity. The image of a distant object level with the lens principal point is thus formed at the lens principal point regardless of the misalignment  $\alpha$ . In practice, the mirror is usually mounted at a constant angle to the vertical and a second mirror fixed to the telescope directs the image to a convenient position for viewing.

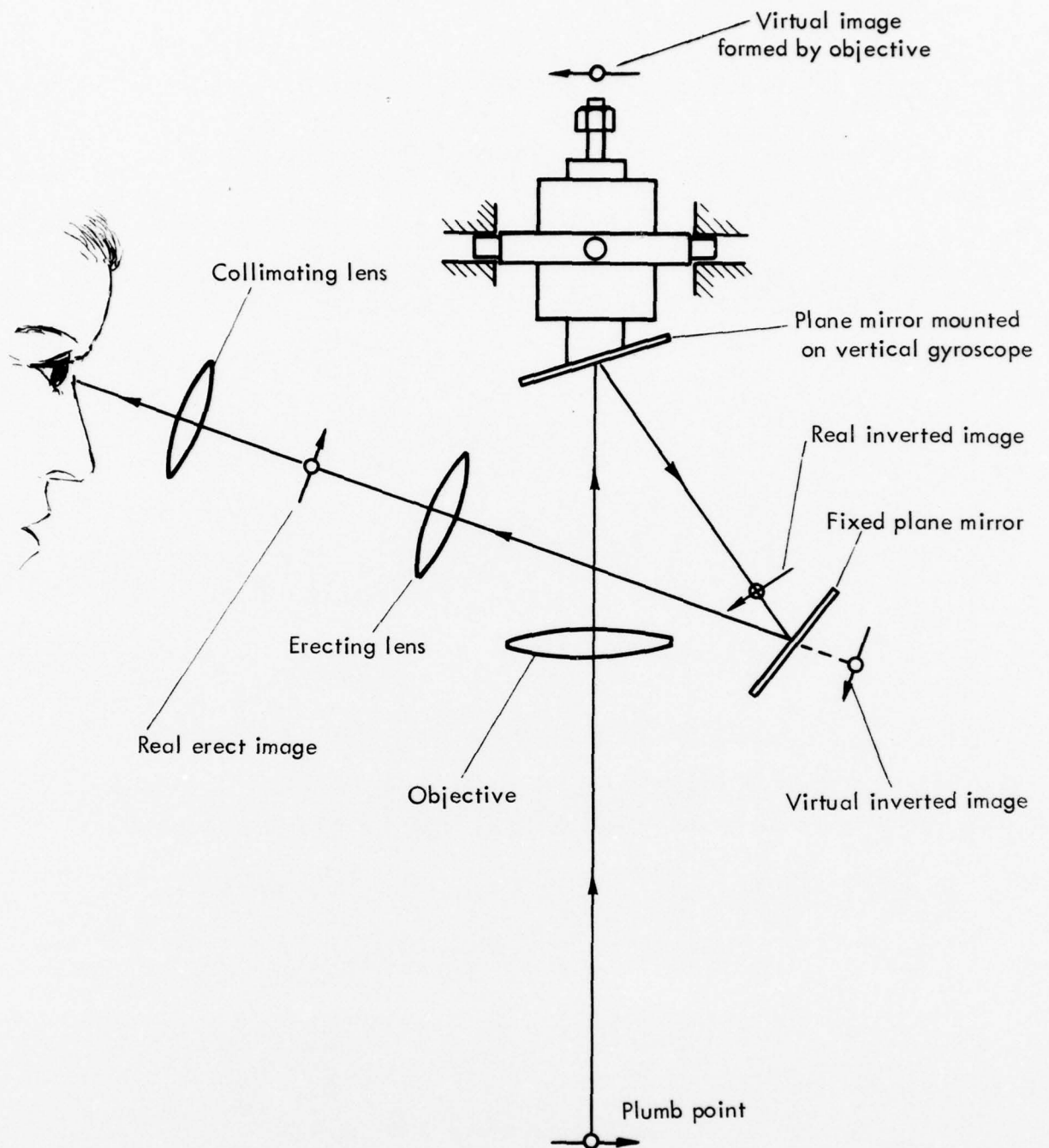


Figure 5 Gyroscopically stabilized plane-mirror vertical viewing device. All optical elements are fixed to the helicopter with the exception of the plane mirror which is maintained at a constant angle to the horizontal by the vertical gyroscope on which it is mounted. A graticule at the position of the real erect image would indicate the plumb point.

- (b) The viewed image is at optical infinity or any other suitable distance.
- (c) The plumb-point indicator (i.e. the graticule mark indicating the gyroscope vertical axis) and the ground image can be superimposed so that pilot head movements would not affect the indication.

Difficulties arise with this system when the practical design is considered, however. Over relatively featureless terrain, a wide field of view seems necessary from previous experience, otherwise the initial acquisition of the target point may take too long. Experience with the ground-based television system indicates that an initial field of view of about  $10^\circ$  or  $15^\circ$  diameter is desirable. Supposing that a value of  $12^\circ$  is adopted, for example, then the lens system should give acceptable imagery over the whole of this actual field of view. The objective has to perform well over a wider field than this, however, because tilts of the helicopter during hovering would bring off-axis regions of the image to the centre of the pilot's field of view. These tilts may also be in the order of  $12^\circ$ , so that the objective's total field of good imagery in this example would need to extend over about  $\pm 18^\circ$ . This means that a simple lens system such as a telescope objective could not be used; rather, a more complex system like a camera lens would be necessary.

The device ought to be usable without the necessity for the pilot to hold his head almost motionless, so that a large exit pupil is desirable. The objective lens diameter has to be equal to the exit pupil diameter multiplied by the magnification of the system, so that the physical size limitations on the objective and stabilized mirror limit both the magnification and allowable head movement. To illustrate the difficulties that arise with this type of system, a design has been performed for an existing aerial camera lens as the objective; its clear aperture is 65 mm and the focal length is 200 mm. If the magnification is chosen to be 2.0, the exit pupil diameter is only 32.5 mm which seems inadequate. A unit-magnification system would be better in this regard.

Preliminary sketches for this design indicated that the relative positions of the stabilized mirror surface and the centre of the gyroscope gimbal system have an important effect on the image plane location when the device is tilted. As direct mounting of the mirror on available gyroscopes would not allow the mirror to be closer than about 50 mm to the gimbal centre, values of 50 mm and larger were considered. The best position for the gimbal centre appears to be 50 mm behind the mirror surface on the normal to the mirror midpoint, as in Figure 6.

Figure 6 shows a serious defect of the stabilized plane mirror system: its tilting image plane and consequent defocusing over much of the field of view. At the centre of the viewed field, a  $\pm 12^\circ$  tilt of the device produces a defocus of as much as 5% of the objective's focal length. At unit magnification, this would require about a 0.25 dioptre change of the observer's accommodation, which, by itself, is of little consequence. The defocus introduces a much more serious effect, however; when combined with the allowed range in head movement (i.e. the exit pupil diameter) and the movement of the exit pupil itself caused by the mirror, the apparent position of the plumb-point indicator can be in error through parallax by as much as  $\pm 26$  mrad. About half of this error is systematic and could be compensated by a suitable small change in the value of  $n$  (Equation 3), but the remainder still seems too large for practical application of the device.

Further difficulties arise when the remainder of the optical system is considered. A  $12^\circ$  field of view requires the stabilized mirror to have the size, orientation and position relative to the lens shown to scale in Figure 6. It is clear that the layout of Figure 5 is impracticable for the field of view required because the stabilized mirror would vignette most of the ray bundle directed between that mirror and the objective lens. The practical alternative would have the fixed mirror and the remainder of the optical path all on the observer's side of the objective. This would require the fixed mirror to be at least 0.2 m long, however, because of the large angles of incidence of some of the rays.

For unit magnification, an erecting lens system of say 100 mm focal length would be required but to collect all the rays for a constant  $12^\circ$  field of view would require a lens diameter of about 300 mm which is impracticably large. The requirements for the viewing (i.e. eyepiece) lens are comparable. Some reduction in size could be achieved by introducing field lenses at the primary and secondary real image positions but only at the cost of increased complexity of the system, increased positive field curvature (which in the case of lenses other than the objective would not change the defocus at the plumb-point indicator), and decreased eye relief.

Laboratory models of this type of system confirmed the practical difficulties associated with



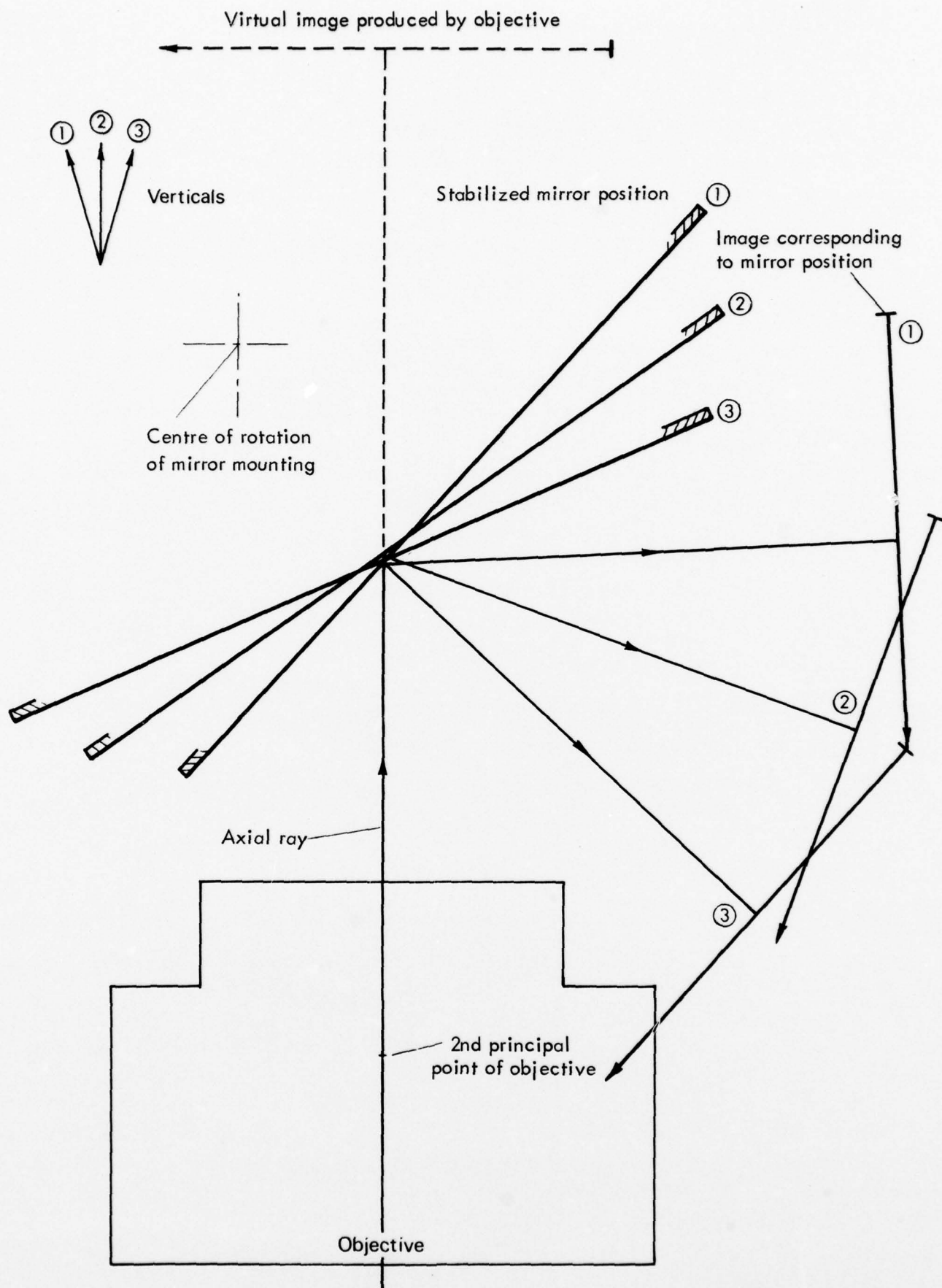


Figure 6 Image positions corresponding to  $-12^\circ$ ,  $0^\circ$ , and  $+12^\circ$  of tilt of the stabilized plane mirror sight. At the central ( $0^\circ$ ) position, the mirror crosses the axis at 0.5 of the focal length from the objective and the centre of rotation of the mirror mounting is on the mirror surface normal from this point.

magnifications of unity or more. The requirements for large lenses diminish as the magnification is reduced below unity but the parallax errors remain unaffected. It seems that this system would not prove successful in providing the field of view, magnification, eye relief and accuracy considered necessary for the purposes mentioned.

Alternative methods of arranging for the viewed image to be erect were tried. The simplest system uses only two mirrors (one stabilized, the other fixed), together with the objective and an optional viewing lens. This system has the characteristic that tilt of the device produces a rotation of the image in its own plane. This would be most undesirable from the aspect of controlling the helicopter with its six degrees of freedom and this optical system is therefore not given further consideration. Other derivatives of the stabilized plane-mirror system suffer from most of the faults already mentioned and the visual version of this system has therefore been abandoned for the time being.

#### 4.2.3 Television version

The use of a fixed diffusing screen was not considered in the previous section because the advantage it confers, that head movements are no longer restricted to the exit pupil diameter, is not sufficient to compensate for either of the consequent disadvantages of reduced image luminance and severe defocusing of the image as the device is tilted. It seems that many of the problems that beset the visual version could be overcome by placing a television camera at the position of the stabilized image but this does not obviate the defocusing problem. The precedent that hovering is possible with the pilot watching a television screen (Ref. 3) encourages further investigation.

Existing small television cameras commonly have a photocathode area of about  $9 \times 12$  mm. For the width of the field of view to be  $\pm 6^\circ$ , for example, a lens of about 60 mm focal length is required. The physical size of present cameras may make the use of such a lens impracticable, and an alternative would be to use a lens of longer focal length, say 200 mm, stabilize its image, and reduce the image scale by placing a suitable positive lens between the mirror and camera. This would not improve the defocus problem, however; at the edge of the field with a  $12^\circ$  tilt, the image blur diameter with a lens aperture of say  $f/4$  would be 44 mrad which is unacceptably large by at least one factor of ten. What is required is an objective lens for which the field has a positive curvature (i.e. concave towards the objective) and the radius of curvature is half of the focal length. Fortunately, lenses can be produced with these characteristics to a good approximation by selecting suitable values for the lens component curvatures, positions and refractive indices. A suitable value of the Petzval sum (e.g. Ref. 13) would give the required field curvature while the other aberrations, including astigmatism, could be kept sufficiently small. Although such a lens would eliminate the parallax error discussed in the previous section, the systematic error in tilt compensation may still be important, depending on the image distortion produced by the lens and its variation with field angle. A field flattener lens would be required close to the final image surface but this would not present much difficulty.

As the design and construction of a multicomponent objective lens is a long process, even with modern computing and glassworking facilities, laboratory trials of this method were not undertaken as the convex mirror device described in the following section appeared to offer more promise. However, the plane mirror device may ultimately prove useful for applications where high magnification is desired with tilt correction limited to a range of a few degrees.

### 4.3 Stabilized Convex Mirror

#### 4.3.1 Concept

If a convex spherical mirror is rotated about a point in its focal surface, the image will naturally remain stationary at this point although the focal surface will also rotate about the point. The ratio  $n$  of Equation 3 again has the value 2. The image is virtual and inaccessible, and if some image-forming relay lens is placed on axis to receive the reflected rays it will also intercept the incoming light and thus prevent observation. An off-axis arrangement, in which the principal ray is always inclined to the convex mirror surface at the point of incidence, could be used to avoid vignetting but with the fields of view required for the present task, the oblique aberrations appear to be much too great for useful application of this method. One practicable alternative requires the use of a beam-splitting mirror. Figure 7 shows the arrangement of a beam splitter and relay lens for observing the stabilized image formed by a convex mirror which is



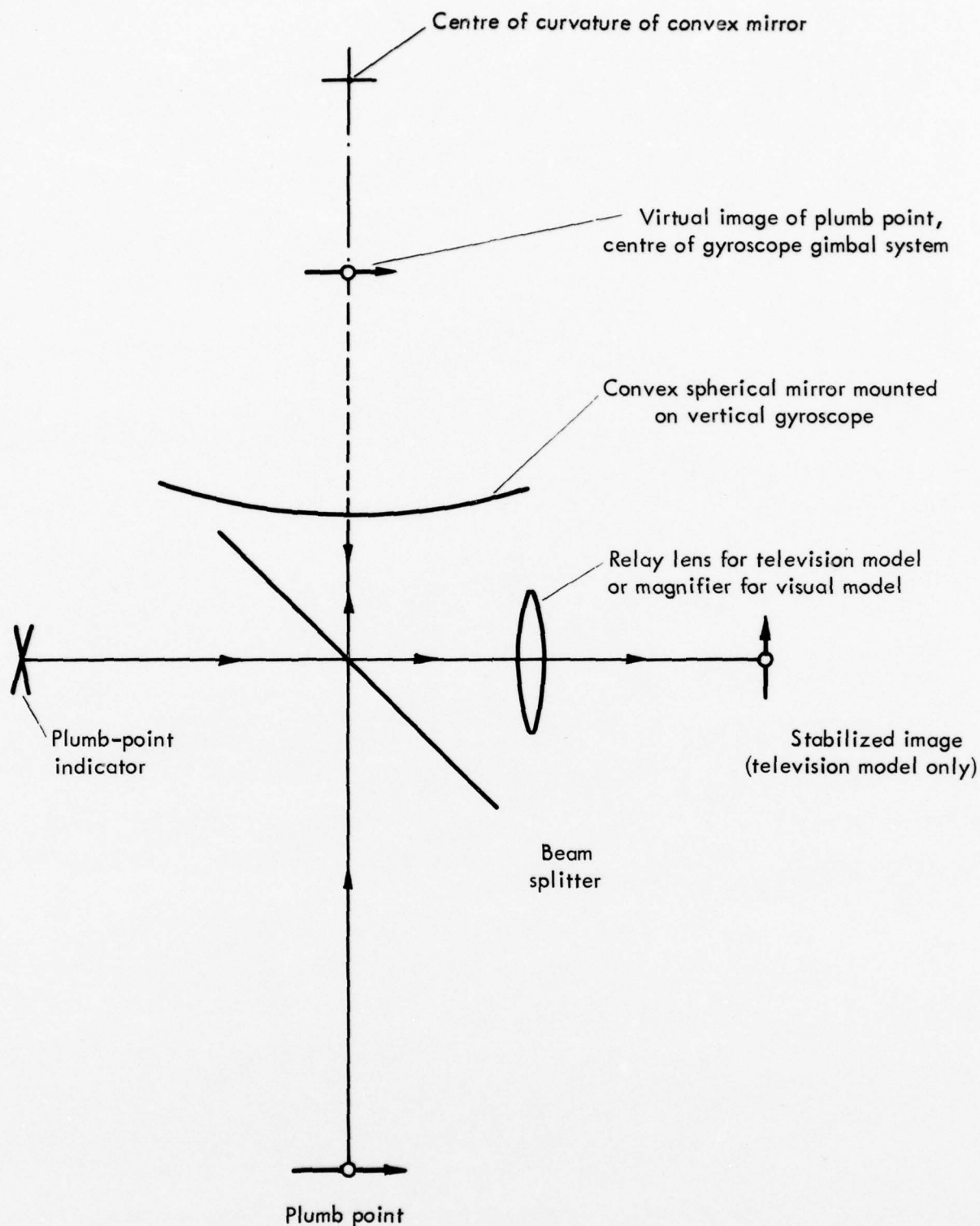


Figure 7 Arrangement of a convex-mirror vertical sight. Light from the plumb point passes upwards through the beam splitter and meets a stabilized convex mirror. This mirror forms a virtual image of the plumb point and its surroundings at the centre of a vertical gyroscope gimbal system. All components except the convex mirror are rigidly fixed to the aircraft structure. For visual use, a magnifier allows observation of the superimposed images of the plumb point and the plumb-point indicator graticule. For television use, a relay lens forms the stabilized image directly on the photocathode.

mounted on a vertical gyroscope. The virtual image is located nominally at the centre of the gyroscope gimbal system.

The accuracy of this convex mirror sight is affected by aberrations and by constructional inaccuracies. The major effects are fortunately all amenable to the simple analysis given here.

(i) *Effect of spherical aberration*

Figure 8 shows ray paths when the sight is tilted. For paraxial conditions, the compensation for tilt is perfect, but with finite angles and apertures, spherical aberration affects the compensation by displacement of the virtual image downwards from the gimbal system centre. The angular error that this introduces is equal to the angular spherical aberration of the spherical mirror for parallel light, viz.  $\sin^3 2\phi$  in third-order approximation (e.g. Ref. 14).

(ii) *Effect of longitudinal displacement of the mirror*

If the mirror principal focus and the gimbal centre are separated longitudinally, i.e. vertically, the resulting error in compensation is zero for zero tilt angle and will increase with the sine of tilt angle. If the longitudinal separation of focus and gimbal centre is  $d$ , the angular error introduced is  $(2d \sin 2\phi)/r$  where  $r$  is the radius of curvature of the mirror. If the gimbal centre is below the paraxial focus the resulting error will be of opposite sign to that introduced by spherical aberration, so that the effects can be cancelled at some chosen tilt angle and reduced at others by suitable placement of the mirror with respect to the gimbal centre. Figure 9 shows this graphically. The curves were chosen to cancel completely for tilt angle  $\theta = 2\phi = 10^\circ$  by equating  $\sin^3 2\phi$  and  $(2d \sin 2\phi)/r$ , giving  $d = 0.01508 r$ . This appears to be a reasonable choice for practical use as the residual error is less than 2 mrad over most of the range of tilt angles likely to be met in practice.

(iii) *Effect of lateral displacement of the mirror*

If the gimbal centre and mirror focus are displaced laterally, i.e. in the horizontal plane, an error in tilt compensation is introduced that is of opposite sign for tilts on opposite sides of the vertical. This contrasts with the previous two cases where the under- or over-correction for tilt compensation was unaffected by which way the device was tilted. For a lateral displacement  $s$ , the compensation error is

$$s(1 - \cos \theta)/r = s(1 - \cos 2\phi)/r.$$

For  $\theta = 12^\circ$ , it would be reasonable to limit this source of error to say 1 mrad. Thus,  $s/r = 0.022$  as an upper limit. This tolerance would not appear to present much difficulty in assembly of a practical device. As this error grows roughly as the cube of tilt angle, for most of the practical range of tilts it can be considered negligible when within tolerance at the extreme working value of tilt.

#### 4.3.2 Visual version

Figure 7 includes the essentials of a visual version of the convex mirror sight. The lens is used as a magnifier or collimator so that a distant, magnified, erect virtual image is formed from the virtual image at the gimbal centre. The indicated plumb-point is marked by a graticule with its centre conjugate with the gimbal centre reflected in the beam splitter. The graticule is thus optically superimposed on the stabilized image so that shifts of viewing position will not introduce parallax errors.

The magnification of the visual version described is best expressed as the ratio of image angles to that of corresponding angles in the naked-eye view of the ground, i.e. angular magnification. This is equal to the ratio of focal lengths of mirror and lens, and geometrical considerations of mirror size and field of view limit this ratio to about 0.5 at most. In a design that is practicable from the point of view of mirror size, clearance between the convex mirror and beam splitter, and distance of the observer from the viewing lens, the apparent field of view occupies  $10^\circ$  and the actual field, about  $20^\circ$ .

A laboratory mockup of the visual version of the convex mirror sight confirmed the limited fields of view attainable. It also showed the existence of a severe problem of multiple reflections of stray light within the device. Rays originating from the immediate surroundings of the observer's eyes as seen from the device proved most troublesome as such rays are returned to the observer via an effective reflectance factor comparable with that applying to the useful rays passing through the device. It was found that the unwanted rays could be virtually eliminated

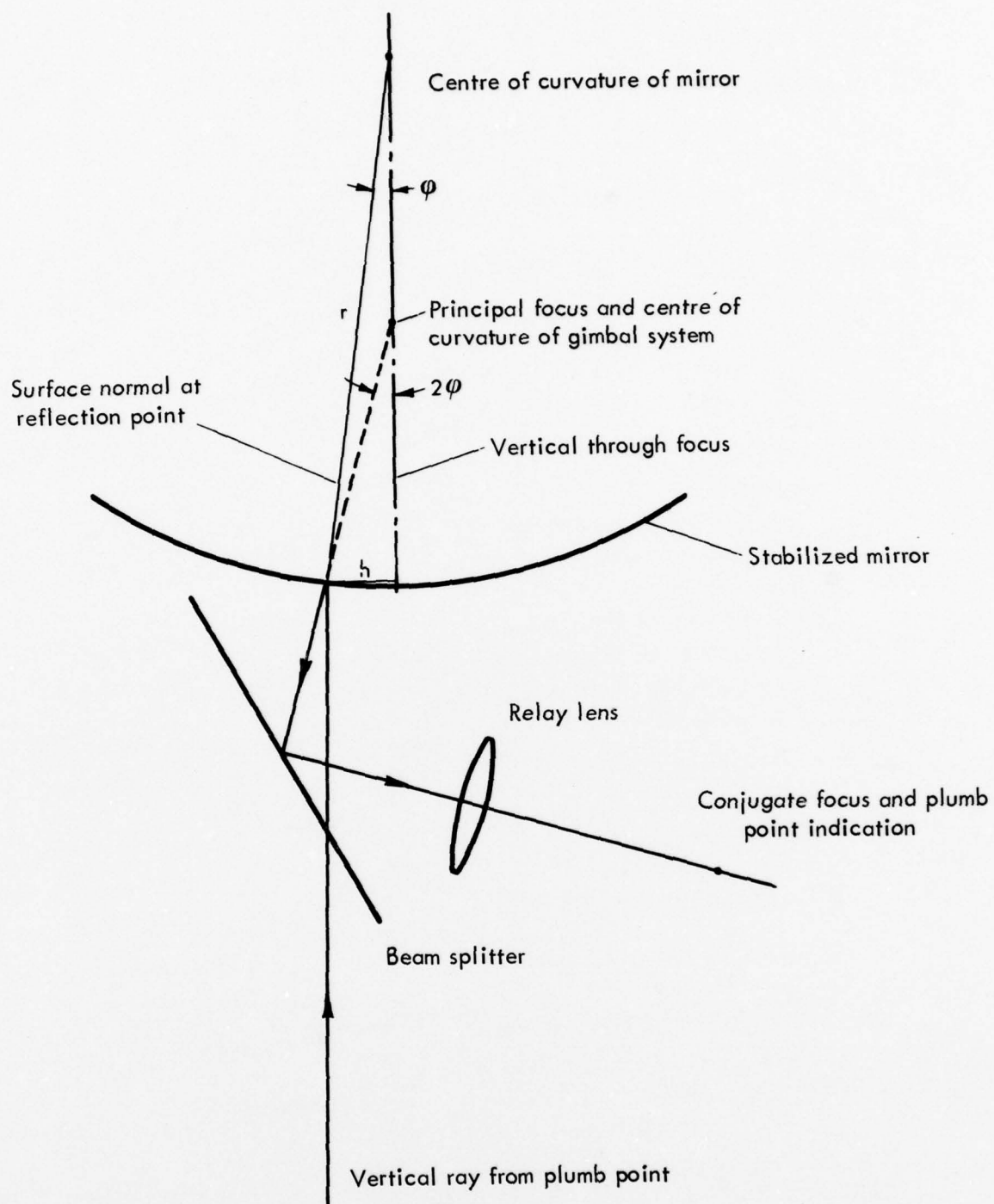


Figure 8 Ray paths with convex-mirror sight tilted.

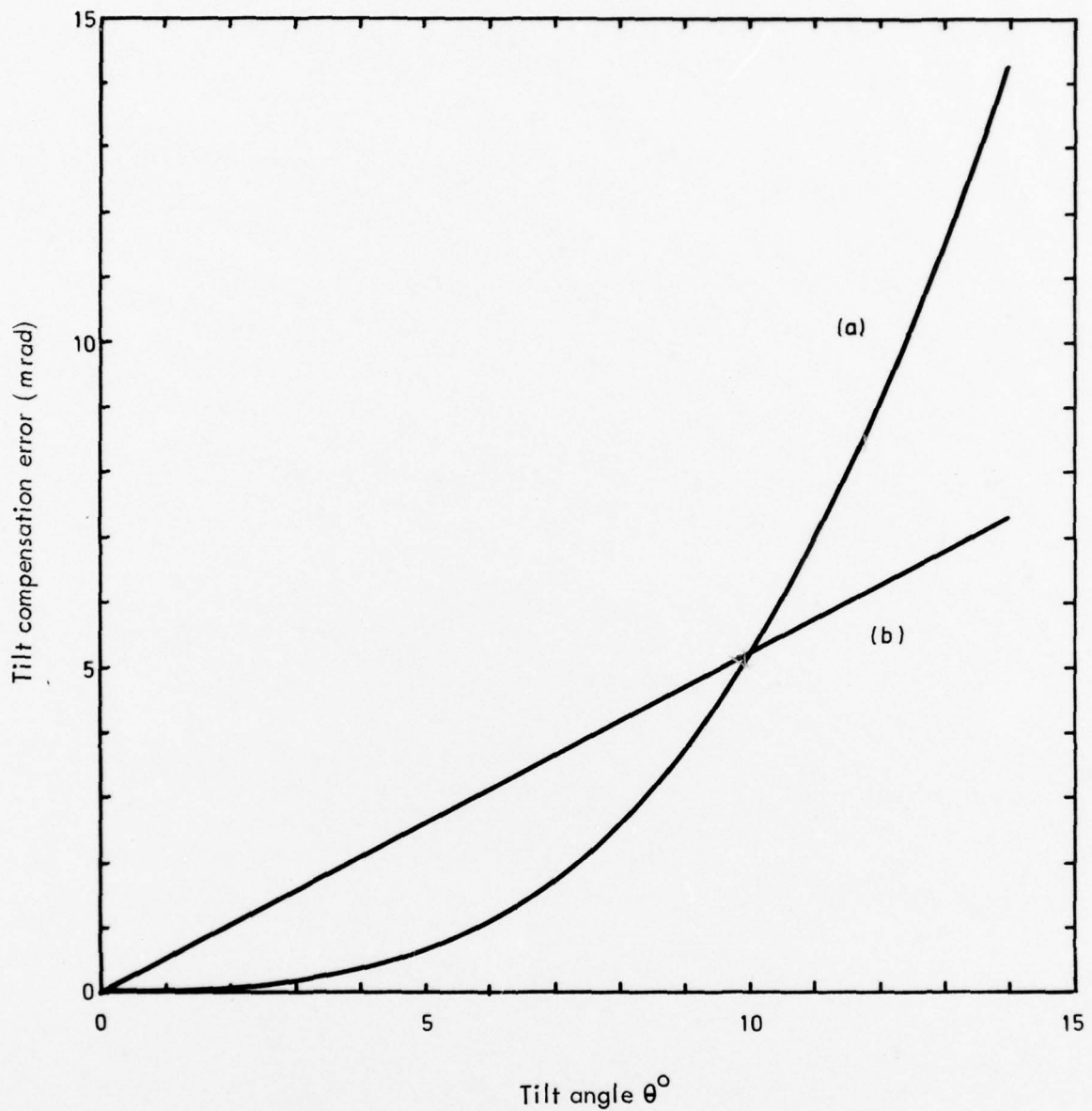


Figure 9 Errors in tilt compensation of the convex mirror sight as a function of tilt angle. Curve (a) shows the effect of spherical aberration and curve (b), the effect of vertical displacement of principal focus from gimbal centre, for a displacement of 0.01508 of the mirror radius. If the gimbal centre is below the (paraxial) focus the effects are of opposite sign and thus tend to cancel.



by keeping the observer's surroundings dimly lit and by inserting a combination linear and circular polarizer sheet as a reflection suppressor in front of the viewing lens. These suppressors transmit only about 35% of the useful light, however, and the effective transmittance of the rest of the optical system is only 20%, so that the luminance of the stabilized image is just 7% of the external field luminance. This relatively dark image would undoubtedly create difficulties for the observer unless he could shield his eyes from the external field. This seems unacceptable for an observer who is also the pilot.

Several attempts were made to devise optical systems that would increase the magnification and actual field of view of the convex mirror sight. As these attempts necessarily involved the use of a real image formed by a relay lens, followed by an erecting system and an eyepiece, complexity was much greater than for the first version of the sight. This added complexity was accompanied by increased effects of chromatic and off-axis aberrations and decreased range of allowable eye movement, to the extent that worthwhile gains in magnification and field of view are not available unless multicomponent lenses of diameters up to 0.3 m are used. The volume and mass of such a version of the convex mirror sight would probably be unacceptably great. This would not necessarily be the case if the requirement for a large eye relief (say 0.5 m) were relaxed: viewing of the stabilized image via a relay lens and a prism monocular telescope has been demonstrated to give excellent imagery without the need for polarizing reflection suppressors, at the cost of requiring the observer to have one eye placed in contact with the eye cup of the eyepiece. Another solution would be to retain the large eye relief and small field of view of the simple convex-mirror viewing lens system, compensating for the optical shortcomings of the device by requiring the observer to wear  $2.5 \times$  telescopic spectacles. The possibility of introducing disorientation with this arrangement would seem likely, however. Further work on visual models of the convex mirror sight was postponed when the first trial of the television version indicated promising results.

#### 4.3.3 Television version

The system of Figure 7 was constructed with a relay lens forming a stabilized image on the photosensitive area of a television camera. The plumb-point indicator was omitted for simplicity in the initial trials. Laboratory tests of the device used a fiducial mark on the monitor screen for assessing accuracy of tilt compensation. Experience with the earlier ground-based television equipment suggests that a graticule on glass placed in contact with the entrance window of the image tube would also produce a satisfactory result. The method shown in Figure 7 is probably the best from the points of view of easy adjustment, accuracy and graticule sharpness, however.

The laboratory tests indicated that tilt compensation was precisely as expected from Figure 9. Superimposed on the compensation error was a fluctuating error of about 3 mrad, the inherent error of the gyroscope. The aluminium-on-glass convex mirror was 60 mm in aperture, 126.4 mm in radius, and 1 mm thick. The gyroscope was an aircraft artificial horizon operated from a 115 V, 400 Hz supply. The whole device was now known as the 'Hoversight' (Fig. 10).

### 5. FLIGHT TRIALS OF THE HOVERSIGHT

#### 5.1 Initial Flight Demonstration

The initial flight demonstration of the Hoversight was made in an Army Bell 47G 'Sioux' helicopter. The wooden box containing the optics and 625 line TV camera was mounted on the starboard landing skid cantilevers within reach of the experimenter in the right-hand seat. A 140 mm  $\times$  185 mm monitor screen was installed on the upper left side of the instrument console facing the pilot. A portable video recorder was also carried. The first flight showed that the pilot was able to hover at 300 m altitude at the first try, despite bad degradation of the monitor image caused by excessive vibration of the box containing the optics and TV camera. This box was supported on anti-vibration rubber mounts that proved too resilient in the helicopter's lateral direction. The next flight was made with another military helicopter pilot and with the box supported more firmly, and again the pilot had no apparent difficulty in positioning the helicopter according to the screen indication of the ground features vertically below. The second pilot commented favourably on the similarity between the angular sizes of ground objects viewed directly or seen on the screen. As in the first flight, the pilot had to cope with poor picture quality. Although the vibration of the optics had been reduced, the ambient lighting was

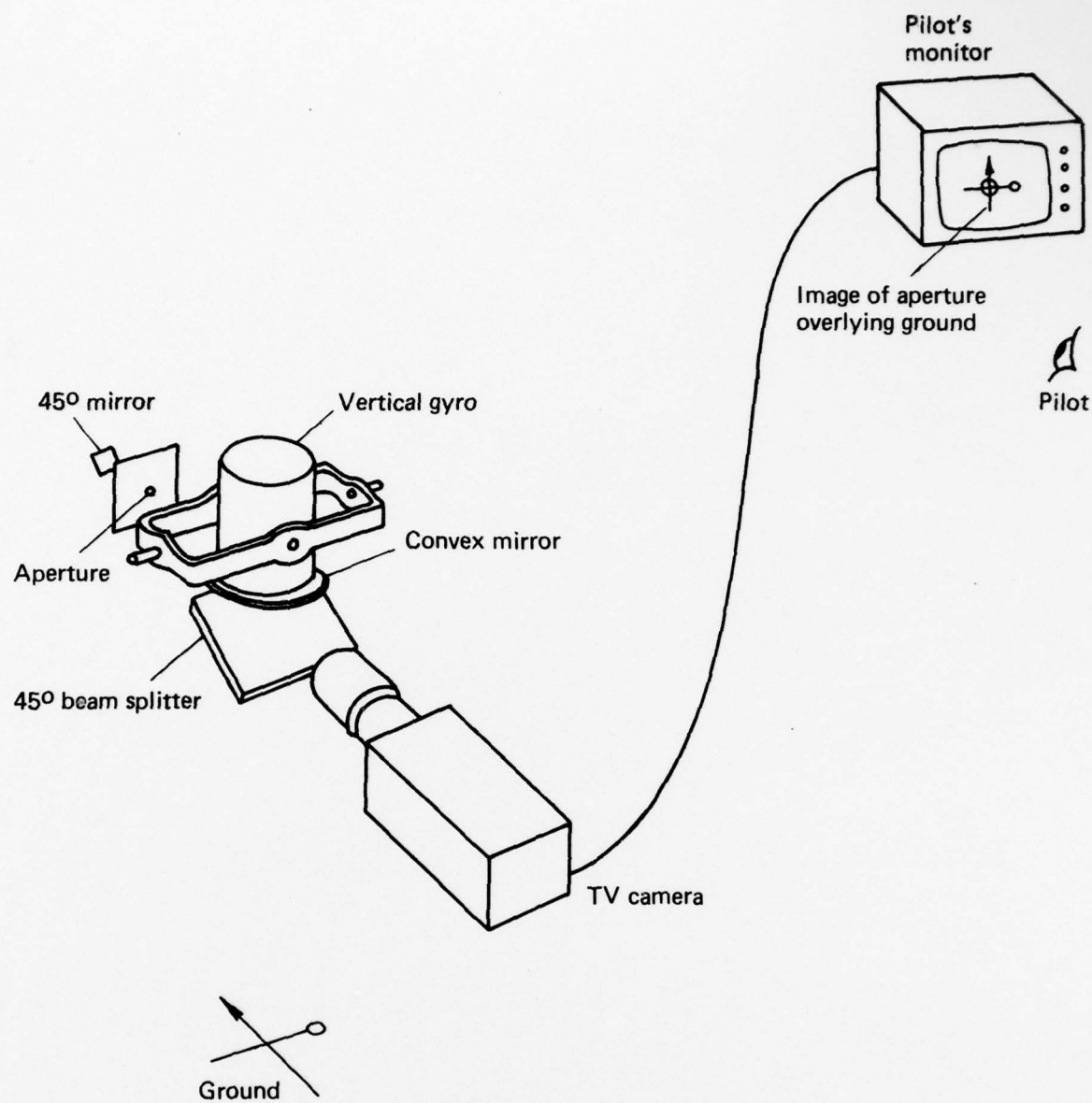


Figure 10 General arrangement of the Hoversight.



greater, and even with the monitor brightness and contrast at their maximum settings the picture was sometimes difficult to see. Despite these handicaps, the practical utility of the Hoversight was now established to the extent necessary to continue its development.

## **5.2 Instrumented Flight Trials**

### **5.2.1 Choice of aircraft**

Arrangements were made with RAAF Support Command for the provision of a pilot, engineering support and 5 hours of helicopter flying at Aircraft Research and Development Unit (ARDU), RAAF Laverton. A Bell Light Observation Helicopter (LOH) was considered for use as the test aircraft but some doubt existed about the extent of modifications necessary to fit the Hoversight, and the continued availability of the aircraft was also uncertain. A Bell 'Iroquois' UH-1B was available, however, and the Hoversight was installed accordingly. Although engineering constraints made the installation less than ideal from an ergonomic point of view, the aircraft certainly proved adequate for the purposes of the trials.

### **5.2.2 Hoversight reconstruction, calibration and installation**

The Hoversight components housed in the wooden box prototype were re-housed in a sheet aluminium case. No major changes were made in the optical system but precise adjustments of the positions of the individual components were now possible. The plumb-point indicator of Figure 7 was first constructed as a target consisting of black cross-lines on a white disc; light from the region of the plumb-point on the ground was intended to illuminate this target by reflection from the beam splitter so that the luminance of the target seen by the TV camera would always bear a fixed ratio to the luminance of the ground as seen by the camera. In this way, the target superimposed on the ground image could always be expected to be visible. During the laboratory calibration, it seemed that the plumb-point indicator was often insufficiently visible on the monitor screen and later experience showed that this would also have been the case in the field. The plumb-point indicator actually used instead was an aperture of 2.5 mm diameter, subtending about  $1^\circ$  at the relay lens. A polished metal surface inclined at  $45^\circ$  to the axis of the relay lens directed light from either the sky or ground through the aperture to the TV camera. Subsequent experience showed that skylight was the better choice, even with the lighting variations resulting from scattered cloud. This is the arrangement shown in Figure 10.

The laboratory calibration served four purposes:

- (i) to bring optical centres and axes into alignment;
- (ii) to check that the gyroscope accuracy was within the manufacturer's limits;
- (iii) to adjust the plumb-point indicator so that it did indicate the true vertical, within the accuracy of the gyroscope; and
- (iv) to allow a measurement of the total magnification of the system.

Item (i) of this list was performed by standard techniques. The remaining items were done with the optics-TV box mounted 2 m above floor level. A plumb bob suspended from reference points on the box allowed the actual plumb-point on the floor to be determined to 0.5 mrad. The plumb-point indicator was adjusted accordingly. The gyroscope was operated for an hour or more on several occasions and the position of the actual plumb-point image on the monitor screen was noted at regular intervals. The deviation between this image and the indicator image was always within the range  $\pm 4$  mrad; this was considered to be satisfactory. Finally the magnification of the system was measured by comparing the length of a scale on the floor with the length of its image on the monitor screen. A small correction was made for the finite viewing distance.

The system was installed in the Iroquois by ARDU personnel in consultation with ARL staff. Briefly, the optics-TV box was mounted on a cantilever beam slung from the starboard auxiliary fuel tank supports, the pilot's monitor screen (200 mm diagonal) was mounted above the left side of the instrument console facing the starboard pilot's seat, another monitor was strapped to the floor in front of the starboard rear seat, a portable video recorder was strapped to the central rear seat, and the 12 V battery and 115 V, 400 Hz rotary inverter (power supply for the gyroscope) were strapped to the floor under the rear seat. Fuller details are given in the ARDU report (Ref. 15). A summary of component dimensions, masses and power consumptions is given in Table I.

The installation was arranged so that the experimenter could operate the system from the

rear starboard seat. The TV camera lens focus and aperture setting could be adjusted through a door on the side of the optics-TV box. These adjustments, together with switches on the side of the box, could be reached in flight without difficulty by the experimenter as all flying was done with the starboard rear door fully open.

From the ergonomics point of view, the least desirable feature of the installation was the positioning of the pilot's monitor screen about 45° in azimuth to the left of his straight-ahead viewing direction. Although the image of the ground on the screen was correctly oriented (i.e. with straight ahead on the ground appearing at the top of the screen), the large displacement of the screen itself from the desirable straight-ahead direction degraded the simple correspondence between directions on the ground and those on the screen. This choice of screen position is understood to have been dictated by the following factors:

- (i) there was insufficient space to mount the monitor inside the aircraft on top of the instrument panel directly in front of the pilot;
- (ii) with some engineering difficulty, the monitor could have been mounted outside the windshield directly in front of the pilot but this would have exposed the monitor, an ordinary portable TV broadcast receiver, to the weather;
- (iii) for most of the trials, only one pilot would be available, and it was therefore important for safety reasons that the visual field of the pilot, particularly the forward and downward view, be no more obstructed than normal; and
- (iv) the actual mounting position used was the best available in respect of engineering convenience, minimal obstruction of cockpit instruments and switches, and crash safety.

One improvement to the monitor over its configuration in the Sioux trials was the addition of a light shield. This was made from blackened corrugated cardboard (for crash safety) lined with black flock paper which is 'dead black' like black velvet. A curved sheet of combination linear and circular polarizer fitted inside the box eliminated most of the unwanted reflections of external scenes from the air-dielectric surfaces in front of the CRT phosphor.

### 5.2.3 Arrangement of flight trials

The helicopter pilot (Flight Lieutenant B. G. Haylock) had over 2300 hours of rotary wing experience including 2000 hours on type. He was employed as a test pilot at ARDU and not long before the present experiment he had hovered the Iroquois for 100 hours in some other trials.

It was decided that the concrete numerals 11 at the threshold of the grass runway 11 at RAAF Laverton would provide a suitable ground target. A 16 mm motion picture camera was mounted horizontally on a heavy tripod between the numerals, and a front-surface mirror at 45° in front of the lens allowed the sky above the camera to be photographed.

An observer from ARL as well as the experimenter was carried in the helicopter on each flight.

### 5.2.4 Flights

Flights with the Hoversight were made in daylight and in mostly fine conditions on 24 June, 1 and 9 August, and 15 October 1974. The gaps between the flights were the result of non-availability of either the aircraft, pilot, experimenters or equipment. Adverse weather also caused some delay, as did the author's desire to investigate some of the results before proceeding with further flying.

Because of the developmental nature of the apparatus and the likelihood of the various delays just described, it was not possible to plan the trials as a completely counterbalanced ergonomics experiment. Insofar as it was possible, however, the accepted principles of such experiments were applied rigorously. For example, no information at all was given to the pilot about his performance either with or without the Hoversight until the full flying program had been completed. The tasks set in the flying program were chosen to provide the data considered most important at that stage. Thus the first flight was used to demonstrate hovering with the Hoversight at 60 m above ground level and then at 600 m. After practice, these hovers were filmed from the ground but not videotaped because of a recorder malfunction. Accordingly, flights at these altitudes were repeated on a subsequent day with both airborne and ground recording equipment operating, first with the pilot using the Hoversight and then with his monitor set turned off but with the videorecorder still operating. This was followed by about 10 minutes of hovering within a metre or two above tarmac markings in a partial simulation

of shipboard landings. (A 25 mm objective lens was fitted to the Hoversight on this occasion.) (The pilot had recently performed actual shipboard landings with a Bell LOH).

Flights on the remaining two days consisted of a series of recorded hovers with and without the pilot's monitor operating, for a range of altitudes between nominal values of 5 m and 600 m. Most of the flights on the last day were made with the 75 mm focal length TV camera lens of the Hoversight modified by the addition of an achromatic Barlow lens to make a telephoto lens of 136 mm focal length.

Three incidents during this phase of the study deserve special mention. Firstly, on the first day of flying, settling with power was experienced while the pilot was manoeuvring close to the desired hover point in gusty conditions at 600 m altitude. Recovery was made at about 400 m. No film or video recording was being made at the time. No other instances of settling with power occurred in the subsequent flights. Secondly, near the end of the planned flights on the third day, the gyroscope was observed to be behaving erratically and observation of the monitor screen showed that the view was many degrees from vertically downwards. The remaining tests for that day were postponed and the gyroscope was later dismantled in the laboratory. The fault was traced to the counterweight that had been added to counterbalance the convex mirror: it had worked loose and was rubbing on the inside of the instrument's outer casing. This time it was fixed in place with epoxy adhesive. The third item concerns the crew. On the last day, an extra pilot occupied the left seat. Both pilots wore a new type of back-pack parachute. This altered the conditions of the experiment and confounded at least two variables: the effects of day of test and increase of lens focal length. However, in view of the likely minor nature of any effect due to wearing the parachute, the existing defects in full counterbalancing of the experimental design, and the added safety with the second pilot on board, no objection was raised.

#### 5.2.5 Observations of pilot

During the trials an ARL observer (K. W. Hendy) sat in a seat between and behind the two pilot's seats. From this position it was possible to observe the instrument panel and the pilot's eyes when he was looking at the monitor screen. For the first two flights the observer noted the pilot's overt behaviour and recorded his comments when these related to the hovering task. In the remaining flights the proportion of time the pilot spent looking at the monitor screen was noted by direct observation of the pilot's head and eye movement.

The pilot's comments in the first minutes of using the Hoversight at 60 m altitude concerned altitude and heading. He claimed to be using '50% outside reference' and was glancing outside the cockpit about once each second. In three minutes the altimeter indication increased from 200 feet to 280 feet (61 m to 85 m) and the pilot complained of the lack of altitude information on the monitor screen. The pilot attempted to devote full attention to the screen but the altitude began to decrease and he overcontrolled the aircraft momentarily. At 600 m altitude, the pilot complained of insufficient screen contrast. Wind heading and velocity varied so much that he seemed unable to devote sufficient attention to the screen. This was when the settling with power incident occurred.

In the second flight, the pilot said that the offset position of the screen made it difficult for him to make the control actions required to reduce the position error displayed on the screen. When hovering without the display as part of the trial, the pilot complained of a lack of visual cues, as much of the external visual field was a generally featureless grassed plain. Although the wind at altitude was varying in speed and especially in direction on this occasion, the pilot stated that the wind made control easier.

Table II indicates the amount of time that the pilot spent looking at the monitor screen in the remaining flights when the monitor was operating. The values as a percentage of total hovering time at each altitude lie between the extremes of 71% and 91%.

#### 5.2.6 Analysis of films

As the ground-based movie camera was not aimed precisely and no method of indicating the precise zenith on the film was used, the analysis of the films had to be restricted to finding the extent of variation of the helicopter's position for each condition of altitude with and without the aid of the Hoversight. A complete 30 m roll of 16 mm film was used for each of the 7 conditions that were photographed. As the camera mechanism was clockwork-driven with a duration of 100 s, the mechanism had to be rewound twice while the helicopter remained on station. Each roll of film recorded a total of 240 s of hovering at 16 frames per second.



The films were measured on a Vanguard motion analysis projector with a digital readout. Four values were recorded: the  $x$  and  $y$  co-ordinates of the lower fuselage beacon (which is close to the mast axis and hence close to the centre of mass of the helicopter), the azimuth of the helicopter's longitudinal axis, and the length of either a landing skid on the low altitude films or the whole fuselage on the remaining films. The co-ordinates and azimuth each had an arbitrary zero.

From the measured focal length of the movie camera lens, the measured magnification of the motion analysis projector and the known dimensions of the helicopter, it was possible to calculate the height of the helicopter above the camera at the ground observation point. A separate determination of this height was possible for every measured frame on all films except the two taken at a nominal 600 m altitude: in these, the image was so small that measuring errors masked any variation in apparent length caused by altitude variation. With the height known, it was then possible to calculate the distances in two horizontal dimensions from an arbitrary origin which was approximately vertically above the ground target. These horizontal co-ordinates were then transformed to a new pair of horizontal axes aligned with the helicopter's mean azimuth for the particular film. This was necessary because wind changes between flights resulted in large differences in mean azimuth on different films. Finally, the displacements of the helicopter from its mean position in two dimensions and its deviation from the mean azimuth were calculated, together with mean and extreme velocities. The results are summarized in Table III.

The calculations were performed by digital computer. Several checks were included in the program to allow detection of input data anomalies caused by transcription errors. Corrections were made where appropriate. A  $t$ -test applied to the mean positions of the helicopter for each camera run within each film proved inconclusive as a way of demonstrating that the camera aiming had not been disturbed by the rewinding of the clockwork drive. However, several of the rewinding breaks in filming coincided with the presence of identifiable cloud features in the background and interpolation of the cloud movement in each case was so regular that any camera movement was imperceptible. This was as expected, for the camera was mounted on a tripod that is quite massive by ordinary photographic standards. A check was also made on the effect of varying the time interval between measurements. From inspection of the films, it was initially decided that it would be adequate for the purpose if only every twentieth frame were actually measured, i.e. the helicopter's position would be sampled at 1.25 s intervals. A check on this sampling rate was made by repeating the calculations with the program arranged for a sampling interval of 2.50 s and again for an interval of 3.75 s. The results proved so little different from the original that the 1.25 s interval appears quite adequate.

The results of Table III were analysed for differences between the monitor-off and monitor-on cases. Table IV shows the method. For each of the nominal altitudes of 61, 152 and 610 m, the values of radius standard deviation (SD) (Table III) for the monitor-off case were divided by those for the monitor-on case. To overcome the differences in actual mean altitude between the cases at each of the three nominal altitudes, the radius SDs were brought to a common basis for comparison by dividing by the corresponding calculated mean altitude. Similarly, the mean horizontal velocity for each flight was divided by the mean altitude for the flight, and this treatment was also applied to the extreme horizontal velocities. The off/on ratios of radius SDs, and mean and extreme horizontal velocity on this basis in Table IV should not be significantly greater than unity if the helicopter movements (as distinct from accuracy of hovering vertically above a designated ground target) are unaffected by whether the pilot's monitor was on or off. A  $t$ -test showed this to be the case for each set of comparisons. The same result is obtained regardless of whether the first two rows of Table III are pooled as is the case in Table IV, or if one or other of the rows is discarded. There are also no significant differences between the cases in respect of the mean horizontal velocity or the standard deviation of the azimuth angle. Although there does seem to be some indication of a trend towards reduced mean velocity as well as a trend towards reduced displacement of the helicopter from its mean position with increasing altitude when the pilot's monitor is on, the trend in extreme horizontal velocity leads to the opposite conclusion. This conflict is not an artifact of the method of processing the raw data, and its practical significance has not yet been determined.

### 5.2.7 Analysis of videotapes

The videotape recorder carried in the Iroquois was used to record the TV camera output



during hovering regardless of whether the pilot's monitor was switched on or off. Hovering attempts were recorded for close to 120 s on most occasions. This time was chosen as a compromise between the need for long recordings for accuracy and the constraints imposed by the limited flying time available. Among these constraints were the desire to avoid rewinding and substituting tape reels in flight and a 20 minute limit on recording imposed by tape length. The need to obtain data for as large a range of heights and conditions as possible also influenced the choice.

The periods recorded on videotape overlap most of those recorded on film but exact synchronism was not achieved nor attempted because:

- (i) the pilot indicated to the ground observer that filming could start by switching on the red flashing beacons, whereas the Hoversight operator commenced timing the videotape recording usually some seconds later, after the pilot had said that the beacons were now on;
- (ii) the film recording had to be interrupted for camera rewinding while the videotape recording was still in progress; and
- (iii) no important advantage would have been gained even if much effort had been put into synchronising the recordings.

The videotapes were analysed in the laboratory after the completion of the flying program. The analysis required a measurement of the amount of time (the inclusion time) that the ground target point was within a given size of circle on the monitor screen. Some of the circles used for this measurement were part of the structure of the plumb-point indicator, and the remainder were fine wire circles taped to the replay monitor screen concentrically with the indicator. The timing was done by an observer with an accumulating chronometric stop-watch. On some of the recordings made when the pilot's monitor was switched off, the ground target disappeared off the edge of the recorded field of view but in all cases it was possible to reconstruct its position moment by moment with sufficient accuracy by turning the replay monitor controls to high contrast, thus allowing identifiable ground features of known position relative to the target to be tracked until the target again became visible.

The angular sizes represented by the seven circles used in the measurements were measured with the laboratory arrangement already used to determine the overall magnification of the Hoversight. Also, for each of the 120 s videotape recordings, the maximum and minimum altitudes were calculated from the screen length of some ground feature of known dimensions, and a mean altitude for that period of the flight was estimated by taking into account the course of altitude variation over each particular 120 s recording. The percentages of the total recording time for which the target was within the various circles in each recording (i.e. the inclusion time percentages) were plotted to give a cumulative frequency distribution of inclusion time percentage against angular size of the various circles. Smooth curves were drawn through the observed points. On each of these curves, the angular size corresponding to a 50% inclusion time was found and these values provide a convenient indication of hovering accuracy. Furthermore, each of these angular field sizes can be combined with the estimates of mean altitude for individual recordings to give, for each condition of the trials, a measure of the linear radius ( $R_{0.5}$ ) of the circle for which the helicopter had an inclusion time percentage of 50%.

Figure 11 shows the observations of  $R_{0.5}$  as a function of mean altitude for the case when the pilot's monitor was off. Figures 12a and b show, to the same scale, the results for the monitor-on case with the 75 mm and 136 mm lenses. It was considered possible that fitting straight lines to the observations could obscure some useful point. On the assumption that some sort of power law might fit the observations better, linear regression analysis was used after recasting the data in log-log form. The regression lines for the three cases are shown in Figure 13. Individual points have been omitted from the figure for clarity. The lines have been terminated at the perpendiculars from the appropriate extreme data points, however.

The regression equations are:

for the monitor-off case,

$$\log A = 1.048 (\log R_{0.5}) + 0.773 \quad (r = 0.904, N = 10, t = 6.66);$$

for the 75 mm lens,

$$\log A = 1.340 (\log R_{0.5}) + 1.105 \quad (r = 0.965, N = 10, t = 11.7);$$

and for the 136 mm lens,

$$\log A = 1.079 (\log R_{0.5}) + 1.153 \quad (r = 0.969, N = 8, t = 11.2);$$

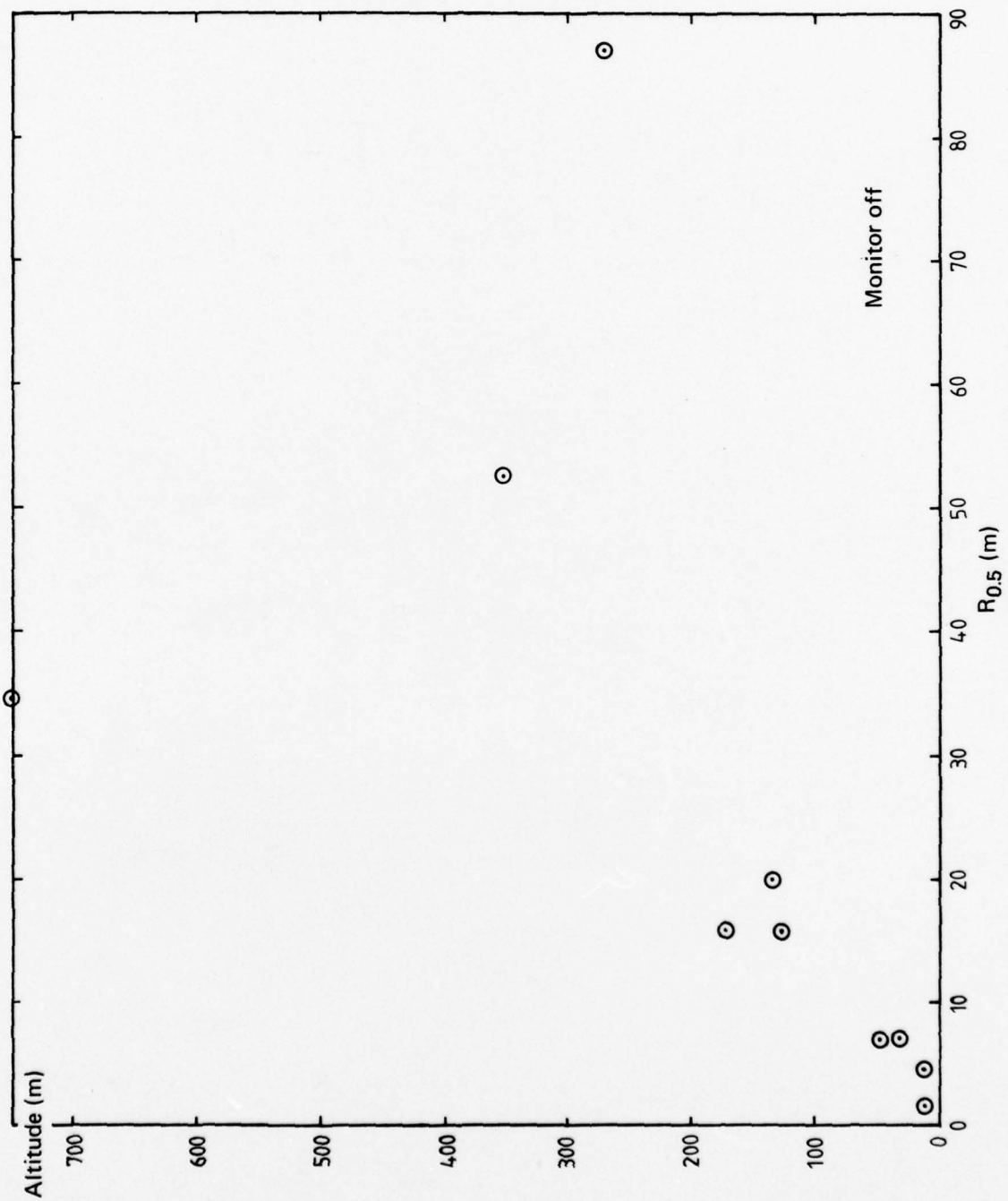
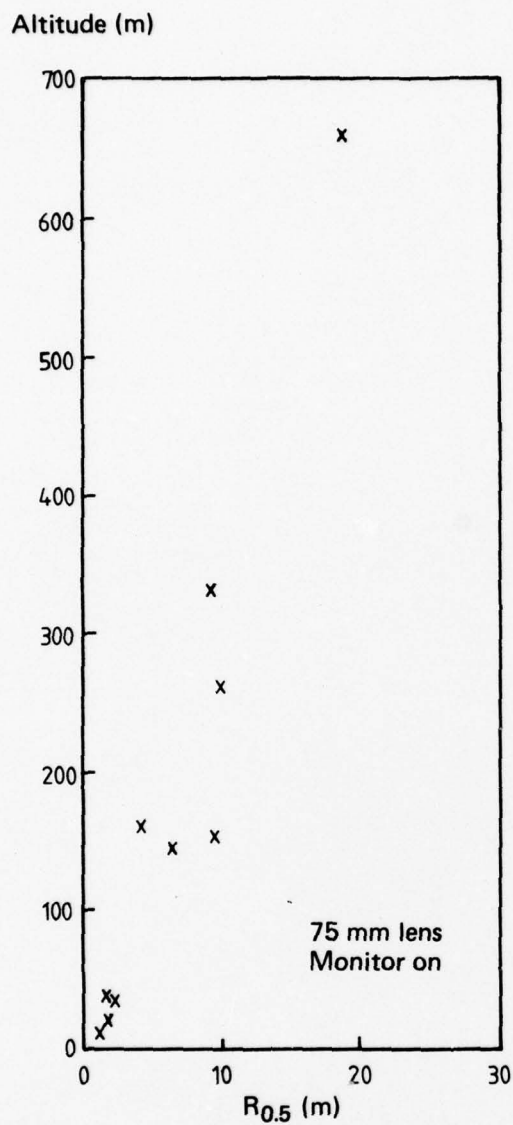
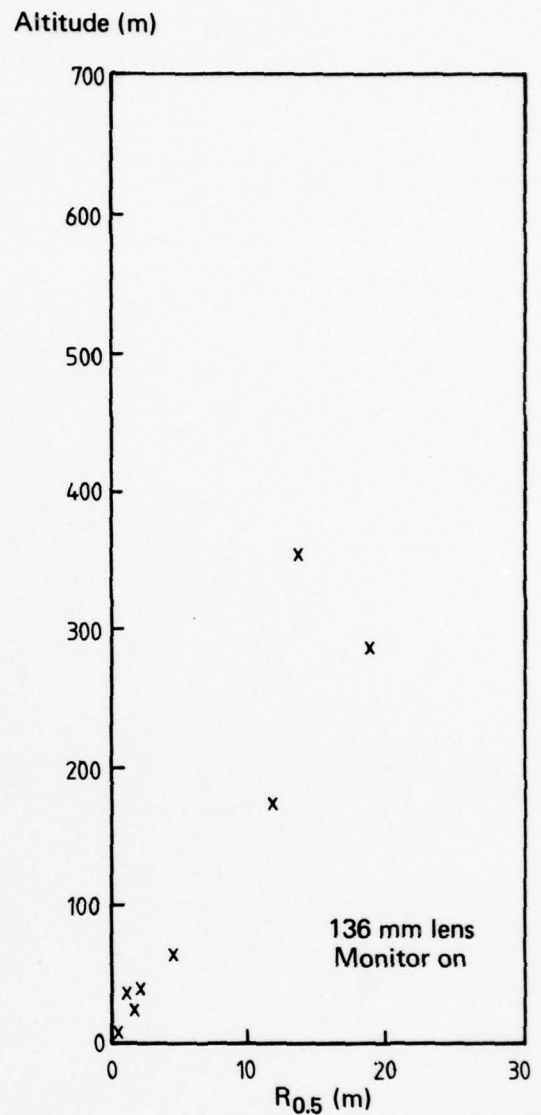


Figure 11 Observations of  $R_{0.5}$  as a function of altitude, monitor off case.



(a)



(b)

Figure 12 Observations of  $R_{0.5}$  as a function of altitude, monitor on case: (a) 75 mm lens; (b) 136 mm lens.

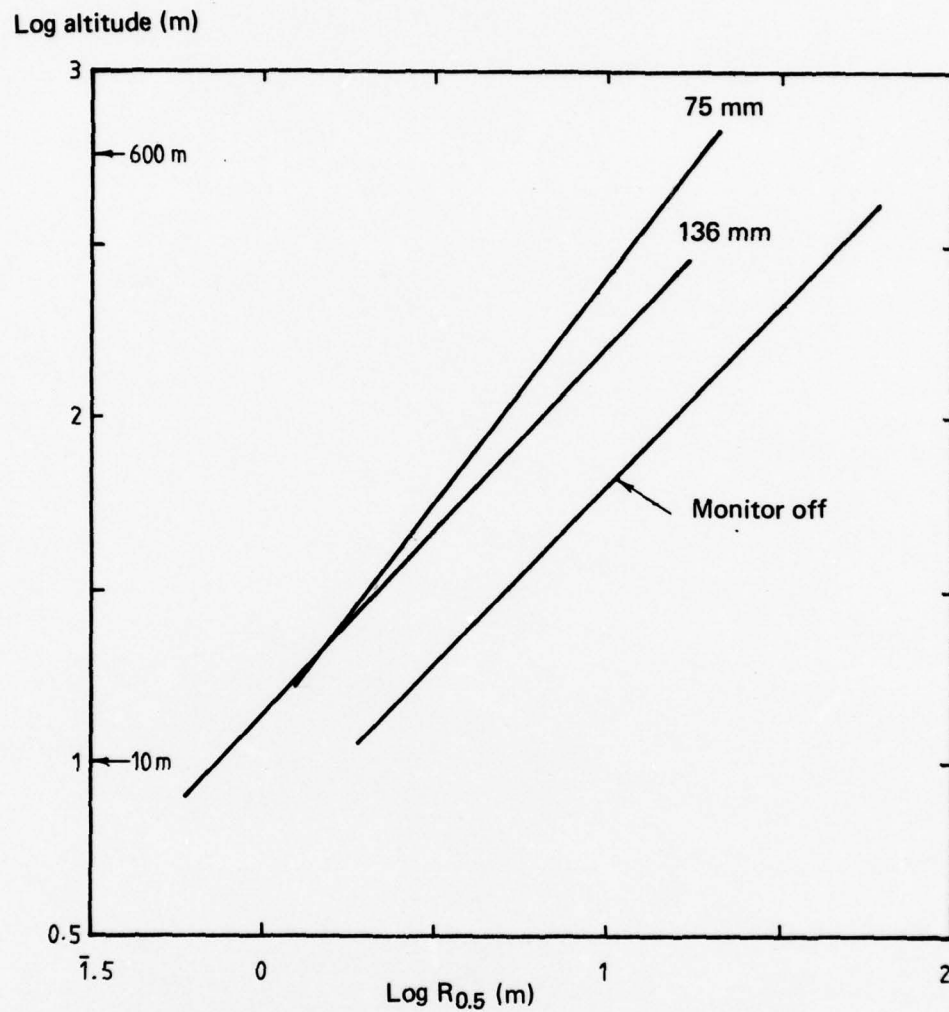


Figure 13 Linear regression lines of log altitude on log  $R_{0.5}$  for monitor off case and both monitor on cases.



where  $A$  is the altitude in metres,  $R_{0.5}$  is the altitude-dependent radius of the horizontal circle occupied for 50% of the time by the helicopter, the centre of the circle being vertically above a designated target on the ground,  $r$  is the correlation coefficient and  $N$  is the number of observations. The values of  $t$  indicate significance at the 0.001 level for all three correlations.

### 5.2.8 Comments

Data taken from near the ends of the regression lines of Figure 13 are given in Table V. From these values it can be seen that the use of the Hoversight with the 75 mm lens improves hovering accuracy by a factor of 2.0 at 10 m altitude and by 4.5 at 600 m altitude. For the 136 mm lens, the corresponding values are 2.3 at 10 m and 2.5 at 600 m. Although a rigorous statistical test of the results would be difficult and time consuming to perform, it is clear from inspection of the graphs that the Hoversight allowed a statistically significant improvement in hovering accuracy compared with the monitor-off condition of the flights. It also seems likely that the superiority of the Hoversight when fitted with the 75 mm lens, by comparison with the 136 mm lens results, is real at the higher altitudes of the tests but at lower altitudes the differences may not be significant. The practical significance of the results is discussed in the next section.

## 6. DISCUSSION

### 6.1 Hoversight Flight Trials

#### 6.1.1 Horizontal accuracy

Under the conditions of the trials in the Iroquois the use of the Hoversight allowed a substantial improvement in the accuracy with which the helicopter could be hovered vertically above a ground target. However, the magnitude of this improvement may have been less if the Hoversight as a hovering aid had been compared with the aid provided in current Air Force practice: a crewman trained to look down at the target and give verbal instructions to the pilot. Although it would have been most instructive to make this comparison, it was not possible because the available number of flying hours was already marginal for the evaluation that was made. This evaluation was considered more important as a means of indicating both the potential and disadvantages of the Hoversight as an aid to be inserted into the pilot-helicopter loop. As the following argument indicates, the Hoversight may be capable of modification that would allow a substantial increase in performance, and until appropriate further development has taken place, a comparison between the Hoversight and current practice would be quite premature.

First, consider the accuracy achieved in terms of the angle subtended at the ground target by the value of  $R_{0.5}$  at a given altitude. With the pilot's monitor operating, the smallest value of this angle in the trials was 33 mrad for 600 m altitude with the 75 mm lens in the Hoversight. However, the accuracy of the Hoversight in indicating the vertical is in the order of 5 mrad so that the question arises as to why the trials result was not much more favourable. Helicopters, including the Iroquois, can certainly be hovered with very small linear excursions when close to the ground, and it has also been shown that even a Bell 47G can be hovered within a metre or so of the true vertical at up to 1200 m altitude when given adequate guidance (Ref. 3). The pilot in the present trials had previously gained many hours of experience in hovering at altitude and this is evident in the excellent results he achieved when his monitor was switched off. Therefore there seems to be no obvious reason why the achieved accuracy with the Hoversight was not much better.

The results of the present trials appear even paradoxical when other facts are considered. At an altitude  $h$  which may be well out of ground effect, the Hoversight fitted with the 75 mm lens allowed a certain accuracy of hovering. At an altitude 136h/75 with the 136 mm lens installed, the scale of the pilot's monitor image would be unchanged and it seems reasonable to expect that the linear accuracy of hovering would also be unchanged, and the angular accuracy actually improved. However, the results show quite clearly that both of these measures were degraded.

Experience with the earlier ground-based system parallels the present finding. In the quest for greater accuracy with that system, progressively longer focal length lenses were used to increase the image scale on the pilot's monitor. Because of the difficulty of initial positioning when the long focal length lenses were used with their consequent small angular fields of view, stepwise increases in focal length were tried. These were not entirely satisfactory for reasons which are only now becoming fully apparent. The best results in these earlier trials were achieved

by using zoom lenses: a ground operator, who was in voice communication with the helicopter pilot, slowly increased the focal length as the helicopter became more closely stabilized over the target.

It is instructive to compare the image scales on the pilot's monitor screens in the two systems. For the ground-based system, Reference 3 states that the TV camera lens focal length had to be about 1/2000 of the hovering altitude. However there is some evidence that the use of even longer focal lengths produced better results, at least at altitudes below about 400 m for which sufficiently long focal lengths were available for the tests. With a suitable combination of focal length and altitude, the width of the pilot's monitor screen could be made to represent a linear distance in the order of 5 m. Using this as a basis for comparison and taking into account differences in monitor screen size and viewing distances, the Hoversight with the 75 mm lens in the Iroquois had a similar apparent magnification when at about 15 m altitude. Interestingly enough, for this altitude and the 75 mm lens, Fig. 12 indicates  $R_{0.5}$  as 1.1 m, comparable with the accuracies attained with the Bell 47G using the ground-based system although this was achieved in the 47G at much higher altitudes.

Perhaps the explanation of the present results is that at low altitudes, as evidenced by the results for the monitor-off case, the pilot used cues from the surrounding terrain to keep the helicopter stable enough in position to derive additional benefit from the Hoversight. Even with the image scale maintained for an increased altitude by a discrete increase in the lens focal length, the pilot had lost some part of the cues previously available when the terrain was closer, again as evidenced by the monitor-off results for increasing altitudes, and this presumably accounts for the reduced performance with the Hoversight. What is implied is that the pilot cannot make optimal use of the information on the monitor screen unless he already has reduced the helicopter's position error and velocity to appropriately small values. The obvious way of trying to overcome this difficulty is to provide the Hoversight with a zoom lens. This provision was actually recognised as desirable before the second prototype Hoversight was built but no suitable lens was available then, and even if it had been, limitations imposed by the dimensions of the other existing optical components may have made much of the zoom range unusable, or at least usable only in bright sunlight on light-coloured terrain. In view of the limited flying time allowed for the present trials, the refinement of having a zoom lens was thought to be not justified. It would certainly be regarded as necessary in any further work, however.

#### 6.1.2 Altitude maintenance

Values of the helicopter's altitude during hovering were derived from subsequent analysis of both the films and the videotapes. These were supplemented by written notes of the altimeter readings during the first three flights. In view of the rather large errors inherent in the determination of altitudes from the films and tapes, especially at the higher altitudes, the agreement between these results is considered satisfactory. The discrepancies between the calculated results and the nominal altitudes are several times larger. The inference is that the altimeter in the Iroquois usually read low, by as much as 30% at the lowest altitudes. When the pilot began to hover at or near the nominal altitude, the actual altitude was usually higher according to the two independent optical records. On three occasions an observer noted the altimeter indications during hovering, and the variation in altitude, e.g. an increase of 30 m during a hover at a nominal 61 m, agreed with the increase in calculated altitude. In this example, however, the altimeter was apparently reading high by about 22 m. The reason for such unexpectedly large discrepancies is unknown but it is possible that it is connected with the precise conditions of wind speed and direction near the ground and at altitude, together with the conditions under which the altimeter was zeroed, the placement of the altimeter vent and the operation of the helicopter with unusually low airspeed at altitude. Certainly, only a minor part of the discrepancies could have been caused by the lack of synchronism of the altimeter readings with the optical measurements and the inherent errors in the optical methods.

Notwithstanding the altitude discrepancies, it is clear that variation of altitude during hovering was much larger than the variation in position in the horizontal plane. The largest calculated range in altitude was 59 m in hovering at a nominal altitude of 122 m. The altitude variations seem generally larger in the cases when the pilot was using the Hoversight but the

available data are insufficient for any meaningful statistical tests of the significance of this difference.

The results of the earlier tests of the ground-based system had already indicated that maintenance of constant altitude during hovering was a problem and the pilots for this reason had suggested that an altimeter should be mounted alongside the monitor screen. When this was done the pilots were better able to maintain a steady altitude. In some later tests, a particularly sensitive indicator was used and this allowed a further improvement (Ref. 4). Although this was known before the present trials began, no attempt was made to provide an additional altimeter for the following reasons:

- (i) it was first necessary to demonstrate that the problem also existed with the Hoversight;
- (ii) the addition of an indicator in the vicinity of the monitor screen would have meant another variable in the experiment; and
- (iii) the choice of altimeter type and position is itself a suitable topic for investigation but only after the utility of the Hoversight has already been established.

It may be that best results could be obtained by incorporating an altitude indication on the monitor screen or by using an aural presentation of vertical speed like those used in high performance sailplanes. Radio or radar altimeters have characteristics (Ref. 16) that might make them particularly suitable as information sources for visual or aural display of altitude or altitude variation.

#### 6.1.3 Hovering accuracy in other trials

Reference 17 describes some tests in which a modified CH 53 helicopter was used in precision hovering over a simulated landing zone in trials of simulated night vision devices. Pilots were instructed to hold a stable hover at an altitude of 23 m for a period of 2 minutes. Movements in three dimensions were measured by theodolites. Most accurate hovering was achieved with the pilot observing a panel-mounted 1023-line monitor screen fed by an unstabilized downwards-pointing TV camera with a field of view of 60°, 120° or 180°. The values of  $R_{0.5}$  were 5.0 m, 5.6 m, and 6.4 m respectively. For the day VFR case (no TV display) the value of  $R_{0.5}$  was 8.4 m. "Despite pilot comments to the effect that they thought they were holding a good hover; the theodolite data showed a consistent tendency for the helicopter to drift rearward while rising in altitude... the CH 53 is a highly stable helicopter with an excellent flight control system... precision hover performance should exceed that obtainable in a less stable aircraft." (Ref. 17). The tendency for slow ascent during hovering was also noted in the present trials. The monitor-off line in Figure 11 indicates a value of 3.6 m for  $R_{0.5}$  at 23 m altitude which suggests that the pilot in the present trials was particularly skilful compared with the three pilots in Reference 17. Whether a less skilful pilot would be better or worse than the present pilot in the improvement of hovering accuracy afforded by the Hoversight is an important question but any claim based on the current evidence would appear to be unjustifiably speculative.

#### 6.1.4 Pilot's comments

The results, discussion and conclusions of the pilot's report (Ref. 15) are reproduced in Appendix 1. Read in conjunction with the present report, it provides an independent view of the prototype system in practice.

One point is worth clarification. In 13. *Vertical Hover Accuracy*, it is stated that "The ARL data also had altitude variations of up to 300 feet between analysed film data and analysed video tape data." As mentioned above in 6.1.2, the measurement errors become rather large at the higher altitudes. On both the films and tapes, there is an approximately constant component of the error associated with the measurement of the image size. At the higher altitudes, the image size is small so that the measurement error becomes larger as a proportion of the image size. This is particularly pronounced for the films as the largest distance available was the length of the helicopter. On the videotapes, the available range of dimensions of ground features was better suited to the technique. As the calculated height is inversely proportional to the image size on the film, this is why a 1 m error in 20 m altitude arises from a film measurement error that could also cause a 30 m error in a 600 m altitude. This is a difficulty inherent in stadiametry, and is one reason for the discrepancy mentioned in the above quotation; another is the fact that the film and videotape recordings were not simultaneous. Differences of some minutes exist in some



cases and these were taken into account in the analysis of the heights and height variations in the trials.

## **6.2 Applications**

With the Hoversight in its present form (but with any required engineering modifications), and on the assumption that the present results are indicative of the performance it will allow for other pilots and other helicopters, it appears that its use for certain military and civil tasks could be advantageous. The military tasks could include aerial photography from reproducible viewpoints, surveying in difficult terrain, artillery fire control, rescue operations (especially over water or at night), navigation aids and radar calibration, construction of bridges, installation and inspection of overhead power and telephone cables, sonar dunking, winching, rappelling, landing in confined areas and pilot training. Many of these applications would also be appropriate in civil operations. Other civil applications include traffic control and surveys, minerals search, police work, television coverage of events, pollution monitoring, resources and city growth surveys, air ambulance landing, and lighthouse calibration. Many of these tasks might benefit further by any increases in hovering accuracy resulting from further development of the Hoversight.

## **6.3 Further Development**

It seems clear that any further development of the Hoversight should include the incorporation of a long focal length zoom lens. As the radius of curvature and the linear aperture of the convex mirror in the optical system govern the dimensions of the other optical components, the linear aperture of the camera lens is limited and the relative aperture of the system is also limited. The zoom lens focal length range has to be selected with this in mind; otherwise, there may be insufficient light for the TV camera. From the experience gained so far, it appears that best results will be obtained with a TV camera in which the design emphasis has been aimed at low light level capability rather than on miniaturization as in the present camera.

Several other improvements would be desirable. The camera lens aperture and focal length adjustment should have remote controls. The structure and mounting of the equipment should be less prone to vibration manifested as image degradation. The monitor screen should be mounted closer to the pilot's straight-ahead line of sight. Higher screen luminance would be desirable. Finally the whole system would need to be made sufficiently rugged and reliable to stand up to the rather harsh environment.

A possible extension of the Hoversight principle is stabilized viewing in directions other than vertically downwards. This has obvious military applications, such as in the 'pop-up' operation of surveillance and armed helicopters. Both for this purpose and for hovering at high altitudes, the plane mirror system of Section 4.2.3 may also be worth consideration, either by itself or as a high magnification adjunct to the convex mirror system.

One further aspect of these devices deserves mention. So far, the effort has been directed towards the evolution of a workable physical system, and ergonomics aspects have been introduced only in terms of what is or was feasible, not optimal. The human operator is an essential active link in the control of helicopter hovering with the aids described. Although automatic hovering may well be possible with some adaptation of the Hoversight, the inevitable increase in complexity, mass and cost may prove unacceptable to the operators of light helicopters as long as the currently simpler alternative of using a human in the control loop is not precluded on the grounds of safety or excessive pilot workload. Finally, there may well be some advantages in developing a visual version of the Hoversight as an alternative to the television version already tested. However, the ergonomics aspects would require careful consideration even in the earliest stages of such a project.

## **7. CONCLUSIONS**

Closed circuit television fed by a simple optical system incorporating a stabilized convex mirror has been demonstrated as a hovering aid for light helicopters. Successful flight tests at altitudes between 5 m and 600 m above ground have been made in which the stabilized image of the ground beneath the helicopter was presented to the pilot on a television monitor screen. With this aid, the accuracy of hovering in the horizontal plane in terms of departures from the vertical passing through some designated ground point was better than without the aid by a



factor of up to 4·5. The accuracy did not reach the limiting value set by the inherent error of the gyroscope so that further improvements may allow even more accurate hovering. The most important of the improvements suggested are firstly the provision of a zoom lens, and secondly, an altitude indication on or near the monitor screen. Even with the present system, the point vertically beneath the helicopter is displayed continuously with an accuracy of a few milliradians, regardless of hovering accuracy. Other stabilized viewing systems seem feasible. There appear to be several possible military and civil uses for helicopters fitted with simple stabilized viewing systems.

### **Acknowledgments**

The investigations described in this report depended on the co-operation of several individuals and organisations and this is gratefully acknowledged. In particular, thanks are due to N.I.C. Instrument Company for providing the air-driven artificial horizon used for the initial laboratory demonstrations of systems for image stabilisation; to Mr K. C. Hendy of Cybernetics Group, ARL for assistance with the electronics parts of the Hoversight system and also for acting as a flight experiments observer; to RAAF Support Command for approval of flying time; and to Aircraft Research and Development Unit, RAAF Laverton for the installation of the Hoversight in the helicopter, for subsequent ground support, and for providing the pilot. The pilot, Flt Lt B. G. Haylock, showed commendable enthusiasm and demonstrated remarkable piloting skill.

## REFERENCES

1. Buckmaster, J. L., Loving, H. B. and Dando, T. O. *Geological Survey Professional Paper* 450-E, pp. 135-135, 1962.
2. Ninow, E. H., Cunningham, W. F. and Radcliffe, F. A. Psychophysiological and environmental factors affecting disorientation in naval aircraft accidents. *AGARD Conference Proceedings* No. 95, Part 1 on The Disorientation Incident, 1972.
3. Clark, B. A. J. and Gross, K. A. Precision hovering by light helicopters at moderate altitudes. *J. Roy. Aero. Soc.*, 71, 791, 1967.
4. Stubbs, J. D. and Sandel, B. Airborne survey control system. Design Study Report, Project L346, Publication No. 52/Pub/71, Army Design Establishment, Melbourne, March 1972.
5. Talley, B. B. *Engineering Applications of Aerial and Terrestrial Photogrammetry*, p. 131. Pitman, London, 1939.
6. Harlow, R. A. Flight assessment of head-up display as a clear weather approach aid. Technical Report 71141, Royal Aircraft Establishment, Farnborough, U.K., July 1971.
7. Fish, R. W. The Type 67 stabilized camera mounting. *Photogram. Rec.*, 11, 5, 1956.
8. Sander, W. Chapter 9, 'The development of photogrammetry', in *Photogrammetry—Collected Lectures and Essays*, edited by O. von Gruber. English edition, Chapman and Hall, London, 1932.
9. Williams, E. B. and Branch, W. J. B. *Air Navigation Theory and Practice*, p. 172. Pitman, London, 1959.
10. Cooper, M. A. R. *Modern Theodolites and Levels*, p. 81. Crosby Lockwood, London, 1971.
11. Clark, B. A. J. An optical plummet. *J. Sci. Inst.*, 44, 744, 1967.
12. Teuling, D. J. A. Electronic image motion compensation in a portable television camera. TH-Report 70-E-13, Eindhoven University of Technology, Holland, 1970.
13. Fry, G. A. *Geometrical Optics*, Chapter 23. Chilton, Philadelphia, 1969.
14. Bouwers, A. *Achievements in Optics*, p. 5. Elsevier, New York, 1950.
15. Haylock, B. Helicopter-Hover Sight. Flight Test Report TI453, Aircraft Research and Development Unit, RAAF Laverton, September 1975.
16. Du Feu, A. N. Altimeters—The way ahead. *Aircraft Engineering*, 47(7), 12, July 1975.
17. Hand, L. M. Recent research on avionics system concepts for low-level night helicopter operations. *Proceedings of Conference on Aircrew Performance in Army Aviation*, 27-29 November 1973, Fort Rucker, Alabama, U.S.A. U.S. Army, July 1974.

**TABLE I**  
**Mass, size and electrical requirements of components of the prototype Hoversight**

Component	Mass kg	Size L × B × W m	Electrical requirements
Gyroscope unit and TV camera	8·9	0·50 × 0·28 × 0·18	Gyro: 110 V, 400 Hz, 75 W at start, 12 W running Camera: 12 V, 0·2 A D.C.
Pilot's TV monitor	4·8	0·35 × 0·25 × 0·23	12 V, 1·3 A D.C.
Rotary inverter for gyroscope	6·1	0·20 × 0·25 × 0·15	In: 24 to 28 V, 20 A at start, 4 A running, D.C. Out: 110 V, 400 Hz, A.C.
Video tape recorder	11·0	0·33 × 0·13 × 0·30	12 V, 8·5 A D.C.
Ni-Cd battery pack for television system	11·0	0·24 × 0·17 × 0·19	13 V max., $7·5 \times 10^4$ C



**TABLE II**

**Record of times that the pilot spent looking at the TV monitor screen while hovering with the Hoversight during three flights. The asterisks indicate occasions when wind turbulence was particularly marked.**

Nominal Altitude m	Time on Screen s	Total Time s	% Time on Screen
5	111	128	87
5	115	142	81
9	82	93	88
9	112	134	84
30	139	160	87
30	119	131	91
61	65	79	82
122	103	126	82
122	116	147	79*
122	101	127	80
152	146	183	80
152	72	102	71*
213	95	126	75*
213	137	163	84
304	91	123	74*
304	113	129	88
		Mean	82.1
		SD	5.6

**TABLE III**

**Results of measurements of films recorded from the ground station. This shows a comparison between horizontal displacements and velocities of the helicopter with and without Hoversight information supplied to the pilot's monitor screen. The respective mean horizontal positions are not necessarily vertically above the ground target.**

Pilot's Monitor	Altitude m			Radius SD m	Horizontal Velocity m/s		Angle SD Degrees
	Nominal	Mean	SD		Mean	Extreme	
On	61	49.8	9.81	4.14	0.60	1.76	3.1
On	61	36.2	5.67	4.07	0.61	1.94	6.8
Off	61	47.4	5.04	4.51	0.50	2.70	7.5
On	152	156	7.03	11.8	1.59	5.64	5.7
Off	152	165	19.1	13.7	1.47	6.96	5.8
On	610	600*	—	24.6	1.51	5.20	9.7
Off	610	600*	—	29.9	1.92	5.71	5.6

\* At this altitude, measurements of helicopter image size were too imprecise to permit meaningful determination of altitude variation.

**TABLE IV**

**Comparisons between measures of helicopter movement calculated from ground-based films.**

Pilot's Monitor	Nominal Altitude	Radius SD Mean Altitude	Ratio Off/On	Mean Hor. Vel. Mean Altitude	Ratio Off/On	Extreme Hor. Vel. Mean Altitude	Ratio Off/On
On	61	0.097 7*	0.974	0.014 4*	0.729	0.044 5	1.270
Off		0.095 2		0.010 5		0.057 0	
On	152	0.075 6	1.095	0.010 2	0.867	0.036 2	1.168
Off		0.083 0		0.008 85		0.042 2	
On	610	0.041 0	1.217	0.002 52	1.26	0.008 67	1.096
Off		0.049 8		0.003 18		0.009 51	

\* Results for two flights pooled.

TABLE V

Comparison of accuracy of hovering above a given ground target as a function of altitude and presence or absence of information from the Hoversight. These data are taken from the regression lines shown in Figure 13.

Condition	At 10 m altitude		At 600 m altitude	
	$\log R_{0.5}$	$R_{0.5}$ m	$\log R_{0.5}$	$R_{0.5}$ m
Pilot's monitor off	0.22	1.66	1.92	83.1
Monitor on, 75 mm lens	1.92	0.83	1.27	18.4
Monitor on, 136 mm lens	1.86	0.72	1.53	33.8



## APPENDIX 1

Extract from RAAF Aircraft Research and Development Unit Report No. TI 453, Flight Test Report, Helicopter-Hover Sight by Flt Lt B. G. Haylock, Laverton, September 1975 (Ref. 15).

### RESULTS OF TESTS AND DISCUSSION

#### General

7. ARL analysis of the results indicated that when using the hover sight the mean horizontal displacement from the desired hover position was approximately one third of that measured when the pilot's TV monitor was not operating. This was not a valid operational comparison since without the sight the pilot had no indication of relative positions of aircraft and target. RAAF helicopter units use crewmen to direct accurate hovering over targets directly below the aircraft, and comparative testing under these conditions would be essential if further testing of the sight was conducted.

#### Engineering

8. Several design and fitment aspects limited the operational capability of this prototype system. The external camera and gyro system required precise positioning to sight between the airframe and the skids using relatively rigid retaining structures to isolate induced vibrations. These requirements made the interchange of equipment between helicopter types (Iroquois and Bell 206B-1) impossible without major structural changes to the retaining framework. The unstreamlined framework added considerable drag in cruise flight. Available cockpit space directly in front of the pilot for the TV monitor varied between helicopter types, again making it unlikely that a single system could be developed which was suitable for all types.

9. The prototype system was operated at full brightness and contrast using a shrouded cockpit screen in an attempt to provide sufficient clarity of the hover target for the pilot. However, these conditions did not give satisfactory definition of targets of similar brightness such as bitumen runways and green grass. The problem was compounded by sunlight reflections on the cockpit monitor which could not be alleviated, regardless of screen shroud size. Production systems would require wider contrast and brightness setting to provide suitable clarity of targets.

#### Hovering Accuracy

10. The hovering accuracy was a direct function of monitor observation time. Division of observation was primarily in three areas;

- a. Cockpit (altitude, engine instruments).
- b. External (attitude, heading).
- c. Television Monitor (hover accuracy).

Since the cockpit television monitor was mounted on the co-pilot's side of the aircraft (owing to space availability) excessive scanning movements were required to cover all of the observation areas. Consequently, at least one scanning area had to be disregarded to provide realistic hovering results. Below 200 feet AGL the TV monitor was closely observed and a co-pilot was used to observe cockpit and instruments. Peripheral vision was suitable for altitude monitoring. Above 200 feet AGL the television monitor was the least observed owing to the vertical accuracy requirements (paragraph 13) and attitude variations associated with station keeping in the naturally higher wind conditions. Hence, the hovering accuracy above 200 feet AGL (apart from the magnification difficulties detailed in paragraph 12) decreased noticeably with increased altitude. At all altitudes the trials hovering accuracy qualitatively did not appear to be as high as the crewman directed hovering technique currently employed within the RAAF.

11. The offset television monitor also caused orientation problems when correcting for drift away from the target. Although the figure '11' on the Laverton grass runway was used as the target, and aligned in the vertical sense on the screen (aircraft heading 290° magnetic), diagonal aircraft movements to bring the target to screen centre were difficult. In most cases, corrections

in hovering position were accomplished by moving laterally and longitudinally to make the resultant diagonal correction. Directional corrections were also difficult, particularly when tracking line features in forward flight. These problems would be alleviated by positioning the monitor directly in front of the pilot.

12. Lenses. For hover heights between 15 feet and 200 feet AGL, the 136 mm lens provided adequate magnification for target sighting and guidance for hovering. Initial target acquisition was extremely difficult when using the sight for the run-in owing to the high magnification but was improved when the 75 mm and 25 mm (wide angle) lenses were employed. However, the 25 mm lens was unsatisfactory for hovering at these heights owing to the small size of the target image. For hover between 700 feet AGL and 2000 feet AGL the 136 mm lens was suitable for target acquisition but had insufficient magnification for accurate hovering. At 400 feet AGL the hovering task was most difficult, as this altitude was the 'crossover' point for the 136 mm lens between limits for hovering magnification and acquisition magnification. A zoom lens system, operated by the pilot, would improve this system and provide greater flexibility and accuracy.

13. Vertical Hover Accuracy. ARL results, measured from image sizes on the ground based films and video recorded tapes, showed large discrepancies between the calculated hovering altitude and nominal hovering altitude. These discrepancies varied from 20 feet at 15 feet hover height to 300 feet at 2,000 feet hover height. The ARL data also had altitude variations of up to 300 feet between analysed film data and analysed video tape data. The inaccuracies at altitudes below 200 feet AGL are inexplicable owing to the visual cues available to the pilot, both peripheral and image size variation with altitude variation. At higher altitudes the visual cues were absent and altimeter cross-checking was the only available altitude monitoring technique. The inherent lag in this system proved dangerous and led to 'settling with power' (uncontrolled, high descent rates recoverable only by entering autorotation) which took up to 1,000 feet loss in altitude for recovery. Incorporation of a radar altimeter beside the monitor, or incorporation of radar altimeter readout with the image on the screen is essential for operations above 200 feet AGL and preferred for altitudes below 200' AGL.

14. Directional Accuracy. Directional hovering accuracy was maintained by use of a directional target (the runway marking: '11'). Although peripheral visual cues assisted directional accuracy below 200 feet AGL, above this altitude loss of visual cues and the diminished image size markedly reduced directional hover accuracy. If directional hovering accuracy was an operational requirement, a magnetic heading readout beside, or on the monitor would be essential.

#### Operational Applications

15. The operational applications for this system considered during the trials were:
- hoisting,
  - rapelling,
  - external load operations, and
  - survey operations.

The hover sight had only limited application for hoisting and rapelling since a crewman is essential during all phases of these tasks and he would be available to assist the pilot with obstruction clearance and position holding. As these operations are normally required only when surface conditions are unsuitable for landing, obstruction clearances from a crewman are essential and this could not be provided by the oversight system. In the test format, the sight was also unsuitable for external load operations since the camera field of view did not include the cargo hook during the hook-up phase. Single crew survey operations, where a helicopter may be required to hover over an inaccessible survey point, was the only operation for which the sight had an application. However, the sight limitations previously discussed would make this an extremely hazardous operation.

#### CONCLUSIONS

16. The television hover sight as tested was unacceptable for helicopter operations. However, many of the detrimental aspects of this system were a consequence of the prototype nature of the equipment and could be improved to an acceptable standard. These were:

- a. insufficient contrast and brightness control to provide clarity of the target image;
- b. lack of zoom lens facility to provide adequate magnification for target acquisition and hovering accuracy;
- c. lack of superimposed radar altimeter information for maintenance of altitude;
- d. lack of superimposed heading information for directional stability; and
- e. poor positioning of the pilot's television monitor requiring excessive scanning.

17. If the television hover sight was to be developed beyond the prototype stage the following engineering aspects would need to be considered:

- a. Interchange of externally located equipment between helicopter types.
- b. Interchange of cockpit TV monitors between helicopter types.
- c. Externally located equipment would require streamlining.

18. Although comparative trials were not flown, the flight tests indicated that the present RAAF procedures using crewman to direct hovering operations would provide more accurate hovering conditions than the television hover sight. Although the sight could have a survey application, single crew survey operations would be hazardous owing to the sight limitations discussed in paragraph 13.

## DISTRIBUTION LIST

### AUSTRALIA

#### DEPARTMENT OF DEFENCE

Copy No.

##### Central Office

Chief Defence Scientist	1
Executive Controller, ADSS	2
Superintendent, Defence Science Administration	3
Defence Library	4
J.I.O.	5
Assistant Secretary, DISB	6-21

##### Aeronautical Research Laboratories

Chief Superintendent	22
Superintendent, Systems Division	23
Divisional File Systems Division	24
B. A. J. Clark (Author)	25
Library	26

##### Central Studies Establishment

Library	27
---------	----

##### Materials Research Laboratories

Library, Victoria	28
-------------------	----

##### Weapons Research Establishment

Library	29
---------	----

##### R.A.N. Research Laboratory

Superintendent	30
----------------	----

##### Air Force Office

D.G. Operational Requirements	31
Air Force Scientific Adviser	32
Library, Engineering (CAFTS), Canberra	33
SENGSO, Support Command, H.Q.	34
Library, A.R.D.U. Edinburgh, Sth. Aust.	35
C.O. A.R.D.U. Edinburgh, Sth. Aust.	36
Library, RAAF Academy, Point Cook	37
Flt Lt B. G. Haylock, RAAF Academy, Point Cook	38
D. Air Force Safety	39
D. Psychology	40
D. Air Force Medicine	41
D. Aeronautical Equipment Engineering	42
D. Aircraft Engineering	43
D. Weapons Engineering	44
D. Support Requirements	45
C.O. 9 Squadron, RAAF Amberley	46
C.O. 12 Squadron, RAAF Amberley	47
C.O. 5 Squadron, RAAF Fairbairn	48



### **Army Office**

Army Scientific Adviser	49
The Bridges Library, Royal Military College	50
U.S. Army Standardisation Group	51
D. Aviation	52
C.O. 1 Aviation Regiment	53
Library, 1 Aviation Regiment	54
D. Psychology	55
D. Survey	56

### **Navy Office**

Naval Scientific Adviser	57
D. Naval Aviation Policy	58
D. Naval Aircraft Engineering	59
D. Psychology	60
C. O. RANAS Nowra	61
Library, RANAS Nowra	62

### **DEPARTMENT OF PRODUCTIVITY**

#### **Government Aircraft Factory**

Library	63-64
---------	-------

### **DEPARTMENT OF TRANSPORT**

Library	65
Mr. R. Ferrari	66
Director of Aviation Medicine	67

### **DEPARTMENT OF NATIONAL RESOURCES**

Secretary, Canberra	68
---------------------	----

### **STATUTORY, STATE AUTHORITIES AND INDUSTRY**

Australian Atomic Energy Commission (Director), NSW	69
C.S.I.R.O., Mechanical Engineering Division (Chief)	70
Library, Mechanical Engineering Division, Highett	71
Qantas, Library	72
Trans-Australia Airlines	73
Ansett Airlines of Australia	74
Hawker de Havilland Pty. Ltd. (Tech. Librarian), Bankstown	75-76
Commonwealth Aircraft Corporation (Manager of Engineering)	77
N.I.C. Instrument Company	78

### **UNIVERSITIES AND COLLEGES**

Melbourne	Surveying Dept.	79
R.M.I.T.	Aero. Eng. Dept. (Mr. H. Millicer)	80
	Surveying Dept.	81

### **CANADA**

C.A.A.R.C. Co-ordinator, Human Engineering (Dr. A. Tanner)	82
--	----

### **FRANCE**

A.G.A.R.D. Library	83
--------------------	----

### **GERMANY**

Z.L.D.I. Library	84
------------------	----

**INDIA**

C.A.A.R.C. Co-ordinator, Human Engineering (Air Cdre S. P. Verma) 85

**ISRAEL**

Technion-Israel Institute of Technology (Professor J. Singer) 86

**JAPAN**

National Aerospace Laboratory, Library 87

**NETHERLANDS**

National Aerospace Laboratory (NLR), Library 88

**NEW ZEALAND**

Air Department, R.N.Z.A.F. Aero Documents Section 89

Transport Ministry, Civil Aviation Division, Library 90

C.A.A.R.C. Co-ordinator, Human Engineering (Mr. A. Melville) 91

**UNITED KINGDOM**

C.A.A.R.C. Co-ordinator, Human Engineering (Mr. R. Thorne) 92

Spares 93-100